Research Topics

Challenges and successes of one health in the context of planetary health in latin america and the caribbean

Edited by
Christina Pettan-Brewer, Daniela Patricia Figueroa, Laura H. Kahn, Andreza Martins, Natalia Cediel and Alexander Welker Biondo

Published in
Frontiers in Public Health
Frontiers in Veterinary Science

ISSN 1664-8714
ISBN 978-2-83251-300-2
DOI 10.3389/978-2-83251-300-2

About Frontiers

Frontiers is more than just an open access publisher of scholarly articles: it is a pioneering approach to the world of academia, radically improving the way scholarly research is managed. The grand vision of Frontiers is a world where all people have an equal opportunity to seek, share and generate knowledge. Frontiers provides immediate and permanent online open access to all its publications, but this alone is not enough to realize our grand goals.

Frontiers journal series

The Frontiers journal series is a multi-tier and interdisciplinary set of open-access, online journals, promising a paradigm shift from the current review, selection and dissemination processes in academic publishing. All Frontiers journals are driven by researchers for researchers; therefore, they constitute a service to the scholarly community. At the same time, the *Frontiers journal series* operates on a revolutionary invention, the tiered publishing system, initially addressing specific communities of scholars, and gradually climbing up to broader public understanding, thus serving the interests of the lay society, too.

Dedication to quality

Each Frontiers article is a landmark of the highest quality, thanks to genuinely collaborative interactions between authors and review editors, who include some of the world's best academicians. Research must be certified by peers before entering a stream of knowledge that may eventually reach the public - and shape society; therefore, Frontiers only applies the most rigorous and unbiased reviews. Frontiers revolutionizes research publishing by freely delivering the most outstanding research, evaluated with no bias from both the academic and social point of view. By applying the most advanced information technologies, Frontiers is catapulting scholarly publishing into a new generation.

What are Frontiers Research Topics?

Frontiers Research Topics are very popular trademarks of the *Frontiers journals series*: they are collections of at least ten articles, all centered on a particular subject. With their unique mix of varied contributions from Original Research to Review Articles, Frontiers Research Topics unify the most influential researchers, the latest key findings and historical advances in a hot research area.

Find out more on how to host your own Frontiers Research Topic or contribute to one as an author by contacting the Frontiers editorial office: frontiersin.org/about/contact

Challenges and successes of one health in the context of planetary health in latin america and the caribbean

Topic editors
Christina Pettan-Brewer — University of Washington, United States
Daniela Patricia Figueroa — Adolfo Ibáñez University, Chile
Laura H. Kahn — Princeton University, United States
Andreza Martins — Federal University of Rio Grande do Sul, Brazil
Natalia Cediel — Universidad de La Salle Colombia, Colombia
Alexander Welker Biondo — Federal University of Paraná, Brazil

Citation
Pettan-Brewer, C., Figueroa, D. P., Kahn, L. H., Martins, A., Cediel, N., Biondo, A. W., eds. (2023). *Challenges and successes of one health in the context of planetary health in latin america and the caribbean*. Lausanne: Frontiers Media SA.
doi: 10.3389/978-2-83251-300-2

Table of contents

frontiers | Frontiers in Public Health

TYPE Editorial
PUBLISHED 23 December 2022
DOI 10.3389/fpubh.2022.1081067

Check for updates

OPEN ACCESS

EDITED AND REVIEWED BY
Muhammad Asaduzzaman,
University of Oslo, Norway

*CORRESPONDENCE
Christina Pettan-Brewer
✉ kcpb@u.washington.edu

SPECIALTY SECTION
This article was submitted to Planetary Health, a section of the journal Frontiers in Public Health

RECEIVED 26 October 2022
ACCEPTED 18 November 2022
PUBLISHED 23 December 2022

CITATION
Pettan-Brewer C, Figueroa DP, Cediel-Becerra N, Kahn LH, Martins AF and Biondo AW (2022) Editorial: Challenges and successes of One Health in the context of planetary health in Latin America and the Caribbean.
Front. Public Health 10:1081067.
doi: 10.3389/fpubh.2022.1081067

Editorial: Challenges and successes of One Health in the context of planetary health in Latin America and the Caribbean

Christina Pettan-Brewer[1,2,3]*, Daniela P. Figueroa[3,4], Natalia Cediel-Becerra[5], Laura H. Kahn[6,7], Andreza Francisco Martins[2,3,8] and Alexander Welker Biondo[2,9,10]

[1]Department of Comparative Medicine, School of Medicine, University of Washington, Seattle, WA, United States, [2]One Health Brasil and One Health Brazil Latin America, São Paulo, Brazil, [3]One Health Latin America Ibero and Caribbean Network, Programa Ibero Americana de Ciencia Y Tecnologia para el Desarollo, Santiago, Chile, [4]Facultad de Artes Liberales, Universidad Adolfo Ibáñez, Santiago, Chile, [5]Department of Veterinary Sciences, Universidad de la Salle, Bogota, Colombia, [6]Princeton Survey Research Center, Princeton School of Public and International Affairs, Princeton University, Princeton, NJ, United States, [7]One Health Initiative Pro-Bono, New York, NY, United States, [8]Department of Microbiology, Institute of Basic Health Sciences, Federal University of Rio Grande do Sul, Porto Alegre, Rio Grande do Sul, Brazil, [9]Department of Veterinary Medicine, Purdue University, West Lafayette, IN, United States, [10]Department of Comparative Pathobiology, Federal University of Paraná, Curitiba, Paraná, Brazil

KEYWORDS

One Health (OH) approach, Latin America and Caribbean, planetary health collaborations, implementation, challenges and successes, One Health Actions, One Health (OH) history, vulnerable communities

Editorial on the Research Topic
Challenges and successes of One Health in the context of planetary health in Latin America and the Caribbean

Introduction

One Health is currently defined, according to the 2021 advisory One Health High-Level Expert Panel, as an integrated, unifying approach aiming to maintain a sustainable balance and optimize the health of persons, animals, and ecosystems, recognizing that humans health, domestic and wildlife health, plant (authors suggest that this term should include other photosynthetic organisms such as algae and some bacteria which also play a key ecological role) health, and the wider environmental health (ecosystems) are closely integrated and interdependent (1). Such an approach mobilizes multiple sectors, disciplines, and communities at different societal levels to work together to foster wellbeing and face health and ecosystem threats while addressing community demands for clean water, energy, and air, safe and nutritious food, and integrated livestock-forest-agriculture systems, all contributing to sustainable development considering climate change evidence. On 17 March 2022, the four international agencies such as FAO, WHO, WOAH, and UNEP (One Health Quadripartite) signed a ground-breaking agreement to strengthen cooperation in a new era of One Health collaboration.[1]

Latin America faces significant challenges in the last decades due to the deep social inequality associated with environmental degradation and biodiversity loss that menace the integral health of the diverse socio-ecological systems. We consider that planetary health's (PH) core values should be addressed in this editorial as its main goal is equity in health, which is related to socioeconomic regional factors. Despite one of the main critics of PH being anthropocentric, focusing only on human health outcomes and limiting the discussions to sustainability from a human utility perspective (2), we identify in most of the articles of this special Research Topic the relevance and connection between human health disparities and worse animal health and ecosystem conservation. In addition, excessive anthropogenic activities have been leading to climate change, air, or water pollution, higher carbon emission, land degradation, and extreme deforestation. PH is crucial in Latin America and the Caribbean countries, and integrated health approaches are pivotal to mitigating climate change and should be considered as a scope of multidisciplinary collaboration under the umbrella of One Health.

One Health encompasses transdisciplinary collaborations from diverse professional backgrounds, disciplines, cultures, authorities, and community leaders for solving societal human, animal, and environmental health problems. Integrated practices are active around the world to overcome complex problems that impact the health of all living creatures, ecosystem threats, substantial biodiversity degradation, and social equity. The United Nations for the 2030 Sustainable Development Goals.[2] aimed at a massive reduction of poverty by 2050 while maintaining environmental sustainability.[3] Veterinarians play an important role toward these goals through their contribution to human and animal health and wellbeing, economic development, and environmental sustainability. As health professionals, we can achieve these objectives of One Health in a peaceful and sustainable environment.

One Health challenges in the context of planetary health

Two major issues were raised with the landmark meeting of the United Nations for the 2030 agenda. First, animals were mentioned only once within the document, and only as a need for genetic diversity of domesticated animals and their related wild species. Animal health includes companion, livestock, and wildlife health and should be a full and standalone topic, as vertebrate and invertebrate animals have a crucial role in planetary health. Second, there is a practical misconception of sustainability as it does not include and/or overlap animal and plant health. According to a United Nations list of examples of sustainability indicators.[4] used worldwide, the only three indicators of animal and/or vegetal health were biodiversity, forest area, and threatened species. The United Nations World Bank has provided a series of World Development Indicators (WDI), comprising a list of about 140 indicators for a sustainable environment of natural resources use and changes in the natural and anthropized environment. Again, such a detailed list involved the use of environmental resources, such as forest, water, cultivable land, and energy, and monitoring of environmental degradation including pollution, deforestation, and loss of habitat and biodiversity, but nothing directly regarding animal use, health, welfare, and balance of domestic, wildlife, and livestock fauna. This comprehensive list with over 40 indicators has included poverty, population stability, human health, living conditions, coastal protection, agricultural conditions, ecosystem stability, atmospheric impacts, generation, consumption, economic growth, and accessibility. Moreover, the other sustainability indicators, such as air, land, water, ecological condition, and human exposure and health, are directly related to human health and the environmental impact of anthropization.

As sustainability has been defined as the fulfillment of the current generation's demands without compromising future generations, ensuring equilibrium among economic growth, environmental care, social wellbeing, and animals were never part of the equation.[5] Thus, a recognized prize-winning sustainable city or region may have been awarded without a single indicator of animal or plant health or wellbeing. Recently, a One Health Index (OHI) has been proposed to correct the limitations of the sustainability index based only on environmental, economic, and social overlapping domains, with few or no animal indicators inserted in the overall formula. In future, the OHI should be part of sustainability, or vice-versa, aiming for a comprehensive and extrapolable index.[6]

Finally, different understandings of the One Health concept and implementation may represent challenges, including the definition and linguistics of prevention and implementation,

1 Available online at: https://www.who.int/news/item/29-04-2022-quadripartite-memorandum-of-understanding-(mou)-signed-for-a-new-era-of-one-health-collaboration (accessed October 25, 2022).

2 Available online at: https://documents-dds-ny.un.org/doc/UNDOC/GEN/N15/291/89/PDF/N1529189.pdf?OpenElement

3 Available online at: https://sdgs.un.org/2030agenda (accessed October 25, 2022).

4 Available online at: http://wdi.worldbank.org/tables (accessed November 12, 2022).

5 Available online at: https://www.un.org/en/academic-impact/sustainability (accessed November 12, 2022).

6 Available online at: https://news.un.org/en/story/2016/03/524202-un-statistical-body-agrees-global-indicators-measure-sustainable-development (accessed October 25, 2022).

much to work and focus on the equal distribution of funding through the interest of individuals, institutions, and countries, overcoming the competition, and bringing more cooperation and collaboration. Meaning that even in linguistics, some say "implementation" as "initiate" while others see it as "development"—The critical part here is that they keep saying implementation in Latin America and Africa what has been implemented already and that is why new groups keep forming and starting from zero and reinventing the wheel instead of funding what has already existed—Which brings separation silos, competition, and disunion instead of the 4 Cs—Collaboration, communication, coordination, and capacity building.

One Health demands for holistic and sustainable solutions—A global experience

Globalization, climate change, population migrations, and growing interactions among humans, animals, and plants in altered environments require that health professionals work together in a collaborative and transdisciplinary approach to improve global health and sustainability. The One Health concept encourages these collaborative partnerships, especially among health professionals from diverse interdisciplinary areas within and between countries. The goal of Global One Health is to achieve optimal global health for all species. For people, health equity and equality, gender, and race inclusiveness, especially among indigenous and minority populations, are essential. Several approaches of integrated health and "One Health" in Latin America are not new ideas, however, the concept is still being discussed, defined, and in many countries, yet to be implemented and applied. As described in this special edition by Pettan-Brewer et al., the One Health experiences in Latin America came from "*grassroots*" movements (bottom to top) through One Health Actions. Similarly, US epidemiologist Calvin Schwabe in the 20th century showed the outcomes and benefits of the "one medicine" through the interaction experiences of public health professionals and the traditional Dinka pastoral societies in 1966, reinforced in 1984, and later the evolved concept of "one health" was cited in 2002 by veterinarian Jakob Zinsstag in Chad, Central Africa, working with the integrated health nomadic pastoralists (3), although the term "One Health" was not coined until sometime between 2004 and 2007 (3).[7]

Latin American and the Caribbean public health professionals also had similar integrated human and animal health experiences in many Latin American countries. For example, the need to work as interdisciplinary teams through the simultaneous study of emerging zoonoses in people and animals, the intersectoral health economics assessment, and working together with rural and indigenous communities. *This has been the main theme of "The challenges and successes of One Health in the context of planetary health in Latin America and Caribbean" in the Frontiers Special One Health Edition.*

Historically, physicians and veterinarians worked together, but during the 20th century, they diverged. Medicine became increasingly reductionistic in its approach to diseases. Veterinary medicine and public health were relegated to second-class status. But with the challenges of the 21st century, the status quo is unsustainable. A collaborative approach became essential for individual and population health. This is the One Health-One Medicine approach, which naturally focuses on zoonotic diseases. One Health goes beyond infectious diseases. As described in this special edition, there is also the importance of governance and indigenous population participation for the success of One Health.

In contrast to other parts of the world, and similarly to Africa, One Health in most Latin America and the Caribbean countries has been practiced every day, especially in less developed and impoverished rural and urban areas where there is a lack of health professionals and a need for medical resources. The special edition included examples of the ultimate needs and examples of "grassroots" community movements working together as a necessity for education, disease prevention, and control. In other words, One Health integrated practices most likely came first, even before the actual concept was formally introduced in Latin America and the Caribbean.

Latin America as inspirational of One Health and planetary health actions ("grassroots")

The 2021 Frontiers Special Research Topic Edition, published in Public Health and Planetary Health journal sections, focused on One Health—*Challenges and successes of One Health in the context of planetary health in Latin America and Caribbean* included 19 articles with authors from 12 countries (Brazil, Chile, Colombia, Cuba, France, Italy, Mexico, Portugal, South Africa, Switzerland, the United States, and the United Kingdom), containing diverse topics from history, concept, implementation, research, education, and practical One Health Actions of integrated health approaches in Latin America and the Caribbean. In this scenario, the special edition has fully accomplished its main objective: a deep theoretical and practical analysis of Latin American issues and ideas on the One Health approach. Studies included owner-dog leptospirosis, malaria vectors, modern planetary health, and One Health of peripheries, unified health system, rabies in the Amazon, veterinary rescue team, biodiversity in higher education, food safety of animal origin, public policies,

7 Available online at: https://onehealthinitiative.com/history-of-the-one-health-initiative-team-and-website (accessed November 12, 2022).

avian influenza virus among Cuban hunters, malaria, canine olfactory detection of SARS-CoV-2, mcr-1 gene, West Nile virus surveillance, historical concept, implementation and approach of One Health in Latin America and the Caribbean countries, social sciences in dam rupture as the worst environmental disaster, antimicrobial resistance, cross-sectoral collaborations, integrated systems for holistic approaches, indigenous health, and needs for curricular changes in primary and secondary education discussions. In addition, out of the 19 accepted peer-reviewed articles, the special edition had two studies from Guadeloupe—A French overseas region in the Caribbean Sea—A cross-sectoral collaboration to inform the implementation of the One Health approach, and an international One Health collaboration of France and Institute Pasteur of Guadaloupe conducting West Nile Virus (WNV) surveillance in a small island state of the Caribbean.[8]

Even if different sectors work differently, the cultures are different, and the approaches are different, ultimately the goal is the same. We have a lot to contribute to One Health. We need to organize and integrate our work—both ways are important: "top to bottom and bottom to top". That is the first message. In this special edition, authors shared experiences in Latin America and the Caribbean from both sides. A second important message is that we have tools—some of which are legally binding, like International Health Organizations, that can help us and we need to rely on them. Because one of the problems we have had for decades is that with the One Health approach, everyone agrees on the principle and concept, but when it comes to implementing them, there is no necessary political will or the financial capacity to develop a One Health unit or intersectoral coordination. Regulations are used as binding instruments and it is much more likely that a One Health Agenda for good governance will be endorsed and used among agricultural, health, and all ministries. It is essential to also have these institutional tools and many times even legal dimensions. On 17 October 2022, at the Global Health Summit, in Berlin, Germany, the quadripartite (Geneva, Nairobi, Paris, and Rome) launched the One Health Joint Plan of Action (2022–2026).[9]

Final remarks and perspectives

A challenge for One Health, and finally with the United Nations Environment Programme joining the tripartite, now known as the quadripartite, is to always include environmental health. Hence, the One Health Joint Plan of Action (see text footnote 9), developed through a participatory process of these four global organizations, provides a set of activities that aim to strengthen collaboration, communication, capacity building, and coordination across all sectors responsible for addressing health concerns at the human-animal-plant-environment interface.

1. The One Health Actions experience in Latin America is an example of bottom-up implementations similar to "grassroots" movements as described in many articles of this special edition and well-elucidated in the article by Pettan-Brewer et al. Unfortunately, even though One Health has been successfully implemented in many Latin American and the Caribbean countries for over 10 years, world recognition and funding is yet not available to continue these projects and initiatives. We hope now that with national and international One Health public policies following the Quadripartite Plan of Action (2022–2026), this important issue will be finally resolved, hence the importance of the Top to Bottom One Health implementation as well.
2. Newer associations and Latin American leaders and co-leader representatives have been very active in sharing their experiences in One Health world organizations: OHLLEP, CABI One Health Publishing, current Frontiers One Health Special Research Topics, International Alliance against Health Risks in Wildlife Trade, and Country Senators and Ministries becoming involved developing public policies and recognitions, World Health Summit 2022, United Nations Nature for Health Expert Advisor, and One Oceans Health (Beyond One Health and One Ocean Kiel Initiative.[10])
3. Language, cultural, and political differences and lack of financial support remain a barrier and a limitation to disseminating and developing the One Health, EcoHealth, and Planetary Health concepts, and integrated health approaches in Latin America and the Caribbean countries.

Furthermore, the scope of the special One Health expert's peer-reviewed collection was achieved beyond expectations inspiring many other special topics in One Health afterward. Pioneering is only for the courageous ones—It takes determination to go through difficult adversity, criticism, and controversial discussion, and yet continue to focus on the final proposal—To transcend cultural and political differences, languages barrier, economic difficulties for research projects and publications, competitiveness, and finally achieve collaborations, partnerships, and inspire transformation. One Health will only succeed if we as humans change ourselves as individuals first, and then we can change humanity to be successful in the One Health implementation and development—From *Ego to Eco*.

8 Available online at: https://www.frontiersin.org/research-topics/13053/challenges-and-successes-of-one-health-in-the-context-of-planetary-health-in-latin-america-and-the-c (accessed October 25, 2022).

9 Available online at: https://www.who.int/news-room/events/detail/2022/10/18/default-calendar/one-health-joint-plan-of-action-(oh-jpa)-hybrid-high-level-advocacy-event (accessed October 25, 2022).

10 Available online at: https://forum.oceandecade.org/events/84158 (accessed November 12, 2022).

In conclusion, this special Research Topic provided multidisciplinary investigations and transdisciplinary Planetary Health and One Health Actions, focusing on relevant topics for Latin America and the Caribbean countries and emphasizing transdisciplinarity in research, outreach, and education. Nevertheless, several challenges remain to be fully addressed and require more attention, particularly the impact of climate change, deforestation, the inclusion of indigenous people's knowledge, and planetary health. Sharing One Health in Latin America and the Caribbean is essential for implementing scientific priorities, supporting national and international public policies, and effective customized decision-making for each and all involved countries. We must recognize Latin American and the Caribbean knowledge, unify One Health experiences, and fortify inclusion and diversity in the One Health Global Leadership.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Acknowledgments

Gratitude to all the authors, reviewers, and editors who participated in this Research Topic.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

1. Adisasmito WB, Almuhairi S, Behravesh CB, Bilivogui P, Bukachi SA, Casas N, et al. One Health High-Level Expert Panel (OHHLEP) - One Health: a new definition for a sustainable and healthy future. *PLoS Pathog.* (2022) 18:e1010537. doi: 10.1371/journal.ppat.1010537

2. Lerner H and Berg C. A comparison of three holistic approaches to health: One Health, ecohealth, and planetary health. *Front Vet Sci.* (2017) 4:163. doi: 10.3389/fvets.2017.00163

3. Zinsstag J, Schelling E, Wyss K, Mahamat MB. Potential of cooperation between human and animal health to strengthen health systems. *Lancet.* (2005) 366:2142–45. doi: 10.1016/S0140-6736(05)67731-8

frontiers in Veterinary Science

ORIGINAL RESEARCH
published: 08 January 2021
doi: 10.3389/fvets.2020.580400

Spatial and Simultaneous Seroprevalence of Anti-*Leptospira* Antibodies in Owners and Their Domiciled Dogs in a Major City of Southern Brazil

Aline do Nascimento Benitez[1*], *Thais Cabral Monica*[2], *Ana Carolina Miura*[2], *Micheline Sahyun Romanelli*[3], *Lucienne Garcia Pretto Giordano*[4], *Roberta Lemos Freire*[4], *Regina Mitsuka-Breganó*[4], *Camila Marinelli Martins*[5,6], *Alexander Welker Biondo*[7,8], *Isabela Machado Serrano*[9], *Thiago Henrique Carneiro Rios Lopes*[9], *Renato Barbosa Reis*[9], *Jancarlo Ferreira Gomes*[1], *Federico Costa*[10,11], *Elsio Wunder*[10,12], *Albert Icksang Ko*[10,12] and *Italmar Teodorico Navarro*[4]

[1] School of Medical Sciences and Institute of Computing, University of Campinas, Campinas, Brazil, [2] Laboratory of Zoonoses and Public Health, Londrina State University, Londrina, Brazil, [3] Centro Universitário Filadélfia - UniFil, Filadélfia University Center, Londrina, Brazil, [4] Department of Preventive Veterinary Medicine, Londrina State University, Londrina, Brazil, [5] Department of Nursing and Public Health, Ponta Grossa State University, Ponta Grossa, Brazil, [6] AAC&T, Consultoria em Pesquisa Ltda, Curitiba, Brazil, [7] Department of Veterinary Medicine, Federal University of Parana, Curitiba, Brazil, [8] Department of Comparative Pathobiology, Purdue University, West Lafayette, IN, United States, [9] Universidade Salvador, University of Salvador, Salvador, Brazil, [10] Fiocruz, Gonçalo Moniz Research Institute, Brazilian Ministry of Health, Salvador, Brazil, [11] Institute of Collective Health, Federal University of Bahia, Salvador, Brazil, [12] Department of Epidemiology of Microbial Diseases, Yale School of Public Health, New Haven, CT, United States

OPEN ACCESS

Edited by:
Lester J. Perez,
University of Illinois at Urbana–Champaign, United States

Reviewed by:
Fabrizio Bertelloni,
University of Pisa, Italy
Josipa Habus,
University of Zagreb, Croatia

***Correspondence:**
Aline do Nascimento Benitez
benitez.alinenascimento@gmail.com

Specialty section:
This article was submitted to Veterinary Infectious Diseases, a section of the journal Frontiers in Veterinary Science

Received: *08 July 2020*
Accepted: *19 November 2020*
Published: *08 January 2021*

Citation:
Benitez AdN, Monica TC, Miura AC, Romanelli MS, Giordano LGP, Freire RL, Mitsuka-Breganó R, Martins CM, Biondo AW, Serrano IM, Lopes THCR, Reis RB, Gomes JF, Costa F, Wunder E, Ko AI and Navarro IT (2021) Spatial and Simultaneous Seroprevalence of Anti-Leptospira Antibodies in Owners and Their Domiciled Dogs in a Major City of Southern Brazil. Front. Vet. Sci. 7:580400. doi: 10.3389/fvets.2020.580400

Although leptospirosis has been considered a major concern in urban areas, no study to date has spatially and simultaneously compared both owner and dog serology in households of major cities. Accordingly, the aim of the present study was to assess the seroprevalence of *Leptospira* antibodies, evaluate associated risk factors and conduct spatial analyses in 565 randomly selected households, which included 597 dog owners and 729 dogs in Londrina, Southern Brazil. Seropositivity by MAT were detected in in 11/597 (1.84%) owners and in 155/729 (21.26%) dogs. The risk factors were evaluated with logistic regression analysis and spatial factors and case distribution were evaluated with kernel density analyses. The sera of 14/155 (9.03%) dogs reacted for more than one serovar with the same titer. Canicola was the most frequent serogroup, detected in 3/11 (27.27%) owners and 76/155 (49.03%) dogs. The highest titer among the owners was 1:3,200 and was detected in the same household with a titer of 1:800 in the dog. Simultaneous owner-dog seropositivity was found in 7/565 (1.23%) households, with three reacted against serogroup Canicola. Positive owners were detected in 4/565 (0.70%) households and positive dogs were detected in 141/565 (24.95%) households. The associated risks of infection for dogs were different from those associated with infection in owners. Risk analyses for Canicola also identified specific factors of infection. Regardless of owner and dog cases were not statistically clustered, the kernel map has shown dog positivity occurrence in the same hot locations and near positive owners. The dependent variable analysis and logit model suggested a greater likelihood of peri-domiciliary contact with *Leptospira*. In conclusion, exposure to *Leptospira* infection was significantly higher in dogs than in their owners and human cases spatially overlapped dog cases, implicating dogs as potential environmental sentinels for this disease. In addition, the associated risk may vary according to serogroup, and the observed simultaneous Canicola seropositivity of owner and dog has suggested intradomicile-transmitted infection.

Keywords: zoonosis, One Health, serovar, epidemiology, kernell analysis

INTRODUCTION

Leptospirosis has been considered a worldwide emerging infectious and zoonotic disease caused by the spirochete *Leptospira* spp., which may persist for months in moist soil and water associated with the presence of *reservoir* animals in nature and accidentally transmitted to human beings (1). *Leptospiras* have been classified into over 300 pathogenic serovars (sv) according to structural antigenic characteristics and in 22 distinct genomospecies based on DNA-DNA hybridization composed of 10 pathogenic species, five intermediate and seven saprophytic species, but without correlations among those classifications. The genomic analysis is more accurate than serology during active infections, however, the serogroup identification by detection of anti-*Leptospiras* antibodies allows the identification of the animal *reservoir* (1, 2). Although the serovars reportedly adapted to specific animal species, such as sv Canicola for dogs, sv Bratislava for swine and sv Copenhageni for rats (3, 4) the association of serovars and mammal hosts has not been absolute, and their cellular and molecular basis remains to be fully established (5, 6).

In a leptospirosis surveillance study conducted from 1996 to 2005 in American countries, of which Brazil, Costa Rica, and Cuba have accounted for 83.1% of the 4,713.5 cases annually notified, Brazil alone has notified 3,165/4,717 (67.1%) cases and 349/380 (91.8%) deaths (7). Another systematic review with studies on leptospirosis incidence from 34 countries estimate that 1.03 million human cases and 58,900 deaths due to the disease have been reported annually, mostly concentrated in slums and other poor urban areas of developing countries (8). Disease endemicity and increased incidence have been mainly located in the Caribbean and Latin America, as well as in Southeast Asia and Oceania (9), despite leptospirosis has been considered endemic (restricted or peculiar to a locality or region) in other areas as well where flooding and other environmental conditions associated with rodent infestation may favor the *Leptospira* life cycle (10).

This pattern of human leptospirosis infection has mostly motivated studies either toward retrospectively confirmed cases (11–14) or socially vulnerable communities (7, 15–17). Although providing crucial information on leptospirosis infection and clinical onset, such contributions may not be epidemiologically extrapolated to other endemic regions located in the more prosperous urban areas of some developing countries (18). Not surprisingly, human leptospirosis cases still occur in areas with a high human development index (HDI) such as Londrina city (HDI: 0.841), northern Parana State (HDI: 0.790), Southern Brazil; this non-flooding urban area also has approximately one-fifth (132/653, 20.21%) seropositivity among the local dogs (19).

Still synanthropic rodents have been indicated as the main *Leptospira* reservoirs for human disease in urban settings (20, 21) the role played by dogs as sentinels or reservoirs has been controversial (22, 23). In this context, the World Health Organization (WHO) has demanded an increase in leptospirosis surveillance to determine global losses, improve surveillance methods and establish effective disease control and prevention (24). In addition, the WHO has called for studies focused on the One Health Initiative, combining human, animal and environmental health (25) in a holistic approach to zoonotic diseases (26).

To date, no study has spatially and simultaneously assessed and compared both owner and dog serology along with their household and correspondent risk factors in urban areas of major cities. Although molecular investigations which determine the evolutionary relationships of *Leptospira* infection between humans and dogs identifying and characterizing the circulating or infecting strains, serology has been a more sensitive indicator of past or present infection (3). Additionally, concomitant serology and spatial analyses performed with titration of human and dog samples may provide a better approach to the evaluation of risk factors, cross infection, and common household environmental exposure.

Accordingly, the aim of the present study was to assess the leptospirosis seroprevalence, the associated risk factors and conduct a spatial analysis in owners, dogs, and their respective households randomly selected of Londrina, a seat city of half-million people in Southern Brazil, which is nationally ranked 38th in population and 145th in human development index (HDI) out a total of 5,570 Brazilian cities.

MATERIALS AND METHODS

Study Area and Population

The target population of this study was the residents from the urban area of Londrina (23°18′36″S and 51°09′46″W), the county seat of a metropolitan area and the second largest city of Parana State, Southern Brazil. Londrina was selected due to its high urban area of 97.00%, high human development index (HDI) of 0.841 (ranked 145th) and high urban population of 543,003 inhabitants (ranked 18th out of a total of 5,570 Brazilian cities). The city is located 608 meters above sea level with a rain forest biome under a subtropical humid climate; average temperatures range from 15.6 to 27.5° Celsius, with yearly average precipitation of 1,630 mm and average relative humidity of 71.10% (27, 28).

Sample Size and Sampling

No data on the seroprevalence of anti-*Leptospira* antibodies were available at the time of the survey, either for human or dog general populations throughout the urban area. Thus, calculations for the sample size were designed with an expected 50% prevalence, 5% accuracy, 95% confidence level, and an initial population of 161,144 households [https://cidades.ibge.gov.br/v4/brasil/pr/Londrina/pesquisa/23/47427?detalhes=true&localidade1=410690] for a final minimum sampling size of 384 individuals, with visits distributed only in urban households using freely available software (EpiInfo 3.5.2, CDC, Atlanta, GA, USA). Inclusion criteria of at least one person and one dog per household were applied. Thus, a final minimum of 461 households was finally calculated due to the 20.0% safety margin of potential participation refusal, dog aggressiveness, inadequate sampling, closed household and commercial or public properties as stores, drugstores, parks, playgrounds, and schools.

The sample was randomly drawn by commercial software (BioEstat 3.0, Belém, PA, Brazil) (29). The sample included conglomerates of four households per block with a calculated total of 115 (461/4) blocks, two blocks per city section of urban planning and a total of 58 (115/2) city sections covered. The researchers were coordinated and guided by professionals from the City Secretary of Health office, which had previously informed the local neighborhoods about the visits, volunteer questionnaires and blood samplings. The inclusion criteria for owners included voluntarily signed informed consent, age 18 years or older, voluntary blood sampling by accredited nurses, and at least one dog in the same household. Domiciled dogs owned by household owner, dogs 6 months or older were eligible for inclusion.

An epidemiological questionnaire was applied to verify and avoid previous vaccination against canine leptospirosis.

Dog blood samples were obtained by a veterinarian following voluntarily signed informed consent by the dog owner. Aggressive dogs were not included for blood sampling due to city regulations on animal and human safety.

Epidemiological Investigation

This was a cross-sectional study, and the risk of infection was investigated with an epidemiological questionnaire, which has been formulated, tested, and applied in previous studies (19). The questionnaires included closed questions on variables associated with owner and dog exposure to leptospirosis and were organized into three blocks: A. socioeconomic-environmental variables, B. personal sanitary habits and behavior, and C. animal behavior and management. The State Minimum Wage was R$ 880.00, equivalent to U$ 264.26 with an exchange rate of 3.33 for US$ Dollar to R$ Real at the time of survey.

Serology

All blood samples were drawn between July 2015 and July 2016; the dog owners and their corresponding dogs were both sampled, and the questionnaires were completed in the same household on the same day. Serum samples were separated and stored at −20°C until they were tested by microscopic agglutination test (MAT), as previously described (5), against the serogroups Australis (serovar Bratislava), Autumnalis (serovar Butembo), Ballum (serovar Castellonis), Canicola (serovar Canicola), Grippothyphosa (serovar Grippothyphosa), Icterohaemorrhagiae (serovars Icterohaemorrhagiae and Copenhageni), Pomona (serovar Pomona), Pyrogenes (serovar Pyrogenes), and Sejroe (serovar Hardjo). Among the 200 available serovars for the MAT tests, the strains have been apparently the same in certain geographic regions. In the present study were selected the most prevalent serovars for human and dog cases in the study region in the past 6 years (19, 30, 31) and its availability as a bacterin.

Dog vaccines commercially available in Londrina city included Imunovet® (Biovet, São Paulo, Brazil), Vanguard plus® (Zoetis, New Jersey, USA), Vencomax 12® (Dechra, Northwith, UK), and Nobivac® (MSD, New Jersey, USA).

Since the present study aimed to compare human and dog exposure to leptospirosis, the selected profile of *Leptospira* live bacteria cultures for MAT was the same for both owner and dog samples. Sera were initially tested at a 1:100 dilution, and then those samples presenting positive agglutination were 2-fold diluted until their final titer (5). Thus, the predominant serogroup was defined as the serogroup with the maximum titer against its correspondent serovar.

Samples with the same titer for two or more serovars and samples from dogs vaccinated within 6 months of the sampling day were considered undetermined and excluded from the risk analyses (32, 33).

Statistical Analysis

A descriptive analysis was conducted using the epidemiologic questionnaire variables based on general serogroup detection. A risk measure was used to assess the intensity of the association with risk factors (OR, odds ratio), and a chi-square test was performed to evaluate statistical significance. For the multivariate analysis, logistic regression models were performed with general serogroup detection as the dependent variable and the risk factors as the independent variables. The stepwise method was used to select the final models. To initiate the model processing, a cut-off $p < 0.20$ in the bivariate analysis was used, and the choice of better multivariate models was based on p-value ($p < 0.05$) and r-square (adjustments) for each independent variable, and the interpretation of final models was based on the adjusted ORs. A household was considered positive when at least one dog or one person is positive. The household positivity was analyzed to access the environmental intra domiciliary risk of infection for both owners and dogs.

Despite the 1-year duration of this study, the single household sampling methodology may have impaired the seasonality assessment. The ages of owners and dogs were tested for adherence to the normal distribution with the Shapiro-Wilk normality test. Both were asymmetric and not normally distributed, so to evaluate the difference between positive and negative samples, the Mann-Whitney U-test was used. These analyses were conducted in the “stats” package of the R environmental software program (34).

Spatial Analysis

Points of data collection were determined by the current addresses, and maps with owner and dog case distributions were produced. In these maps, census sector data from IBGE database (free spatial database from Brazil) were also used [https://censo2010.ibge.gov.br/sinopseporsetores/], and flooding, green and water area data were obtained from official database from the city. The density of dog cases was evaluated with kernel density analysis to determine hotspots and compare with potential clusters of owner cases. Flooding and water areas were also concomitantly plotted on the maps to evaluate their spatial association with the data. Despite the effect of green and water areas have not assessed through the regression analysis, flooding has been included as accumulated water in the regression analysis These spatial analyses were conducted using R software environmental with the “epiDisplay,” “spatstat,” and “maptools” packages (35, 36).

The first step was to estimate a logit without considering any spatial effects. Residues of logistic regression have shown spatial correlation. Moran’s I test applied for testing whether residuals of regressions were spatially clustered, with a statistically significant value of 0.09 ($p = 0.002$) for a matrix of weight with the nearest neighbor. Such outcome requested a spatial analysis. Several spatial weight matrices were tested to verify whether the regression residues had significant Moran’s I statistics.

Following, a multivariate analysis of spatial regression has been applied to identify variables explaining prevalence of leptospirosis in dogs. Independent variables included a dummy to register the presence of any reagent human to leptospirosis in the household (Presence of a positive human); whether the dog was vaccinated within the last 6 months (Vaccine); whether the dog had outdoors access (Street Access) or with other dogs inside the household (More than one dog in the house); number of dogs living in the household (Presence of dogs); dummies capturing income range of dog owners (Income2 and Income3); number of people living in the household (Households). Important to mention that the spatial multivariate model had a different specification from the first logistic models, with some very highly correlated variables.

In addition to the above independent variables, two factors were also added (FACT_1 and FACT_2) which represented a linear combination of variables with strong multi-colinearity, including (i) dummy indicating presence of wasteland near the household (Wasteland); (ii) dummy indicating whether the household has outside bathroom (Bathroom outside); (iii) number of rats seen at the yard (Rats); (iv) frequency of yard cleaning (Clean backyard); (v) dummy indicating whether yard had rats (Rats_at backyard); (vi) trash seen at the yard (Dirty backyard); and (vii) whether yard had rubble (Trash at backyard). Factorial analysis was applied to test the above factors.

To calculate the factors from factor analysis, was used to calculate the tetrameric correlations by the maximum likelihood estimator (iterative) obtained from the bivariate probit, using the Edwards and Edwards estimator as the initial value (37). The uniqueness was tested to verify how much of the common variance each variable may represent. In other words, high uniqueness may suggest that the extracted factors may have described the variables well. The results of the factorial analysis made it possible to transform the seven variables mentioned above into two factors (FACT_1 and FACT_2) according to **Table 1**.

As the errors of logistic regression showed a special correlation, it was important to estimate an econometric model taking into account the space so as not to omit a relevant variable.To incorporate a term of the spatially lagged dependent variable into the explanatory variables, the spatial autoregressive model (SAR) estimated by means of maximum likelihood and generalized method of moments was used. The SAR model can be specified as:

$$y_t = \rho W y_t + X_t \beta + \varepsilon_t \tag{1}$$

where ρ is the auto-regressive lag parameter ($-1<\rho<1$) and $Wy_t = (Wy_{1t}, \ldots, Wy_{Nt})'$ is the vector of the lagged dependent variable; $X_t = (X_{kt}', \ldots, X_{Nt}')'$ is a matrix of observations of explanatory variables and $\beta = (\beta_1, \ldots, \beta_k)'$ it is a vector of parameters to be estimated.

A second group of models was called the spatial error model (SEM), where the spatial dependence was considered residual and represented by the first-order autoregressive structure in the error term (37). The SEM model can be expressed as follows:

$$y_t = X_t \beta + \xi_t \tag{2}$$

$$\xi_t = \lambda W_2 \xi_t + \varepsilon_t \tag{3}$$

In which ε is a multivariate normal distribution with zero mean and covariance matrix $\sigma^2 I$; the coefficient λ represents the parameter of the spatial autoregressive error. In the SEM model, errors represent an average of errors in neighboring regions plus a component of random error.

The presence of the spatially-lagged dependent variable (Wy) was equivalent to the introduction of an endogenous variable, using the ordinary least squares method as previously described (38). All estimates were presented to identify the variable robustness.

TABLE 1 | Matrix of components and commonality of indicators.

Variable	Factor 1	Factor 2	Commonality
Wasteland	0.16	-	0.97
Bathroom outside	-	0.29	0.90
Rats	-	0.72	0.27
Clean backyard	0.66	-	0.36
Rats_at backyard	-	0.54	0.70
Dirty backyard	0.93	-	0.04
Trash at backyard	0.87	-	0.08

A map illustrating the municipality of sampling of the studied regions (source: free access Brazilian databases https://downloads.ibge.gov.br/downloads_geociencias.htm) was produced by authors, using these free open access shapefiles and performed on GIS software using ArcGIS 10 and presented (**Figures 1**, **2**).

Ethical Aspects

This study was approved by the National Human Ethics Research Committee (protocol number 1,025,861/2014) and the Animal Use Ethics Committee (protocol number 181/2014), both at Londrina State University, Southern Brazil. In addition, the present study was approved by the Londrina City Secretary of Health and was officially included as part of the annual activities. In addition, all interventions were authorized by the Human Beings Ethics Studies Committee (protocol number 1,025,861) and the Animal Use Ethics Committee of the State University of Londrina (protocol number 181/2014).

RESULTS

A total of 750 households were visited, and the minimum sample size calculation was surpassed with 565/461 (122.56%) households; a total of 597/1,985 (30.07%) owners and 729/1,170 (62.30%) dogs sampled. Overall, 11/597 (1.8%) owners and 155/729 (21.3%) dogs were identified with anti-*Leptospira* titers by MAT, which represented 141/565 (25.0%) of the sampled households (**Table 2**).

Canicola was the most frequently reactive serogroup in dogs, with titers identified in 76/155 (53.9%) samples, followed by serogroups Autumnalis and others with 65/155 (41.9%) sample positivity. On the other hand, Autumnalis was the most frequent serogroup in owners, found in 4/11 (36.36%) positive samples, followed by Canicola in 3/11 (27.27%) positive samples and other serogroups found in 4/11 (36.36%) positive samples (**Table 3**).

In 70/141 (49.64%) households, either owners or dogs were reactive to serogroup Canicola, and 71/141 (50.35%) were reactive to at least one of the tested serogroups (**Table 2**). The highest titers were 1:12,800 for dogs and 1:800 for owners, both to serogroup Canicola; other serogroups reached an equally high titer of 1:1,600 for dogs, but the highest titer was 1:200 for dog owners (**Table 3**).

Simultaneous dog owner and dog seropositivity was found in 7/565 (1.23%) households, of which three were reactive for serogroup Canicola in owners and dogs, and different serogroups were observed in four households. There were 4/565 (0.70%) households that had only owner-positive samples, and only

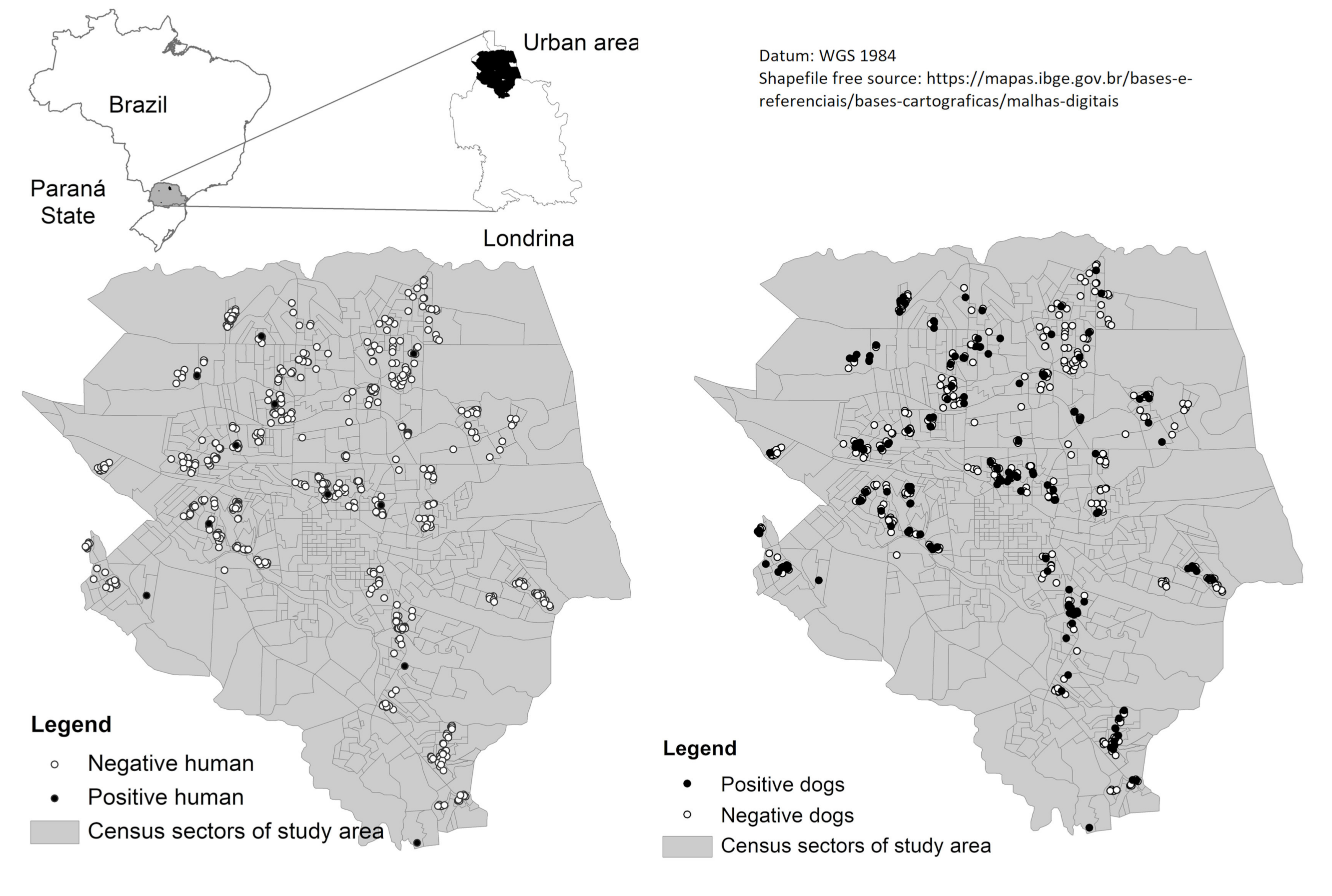

FIGURE 1 | Distribution of owners and dogs positive and negative for *Leptospira* from July 2015 to July 2016 in the urban area of Londrina, Southern Brazil.

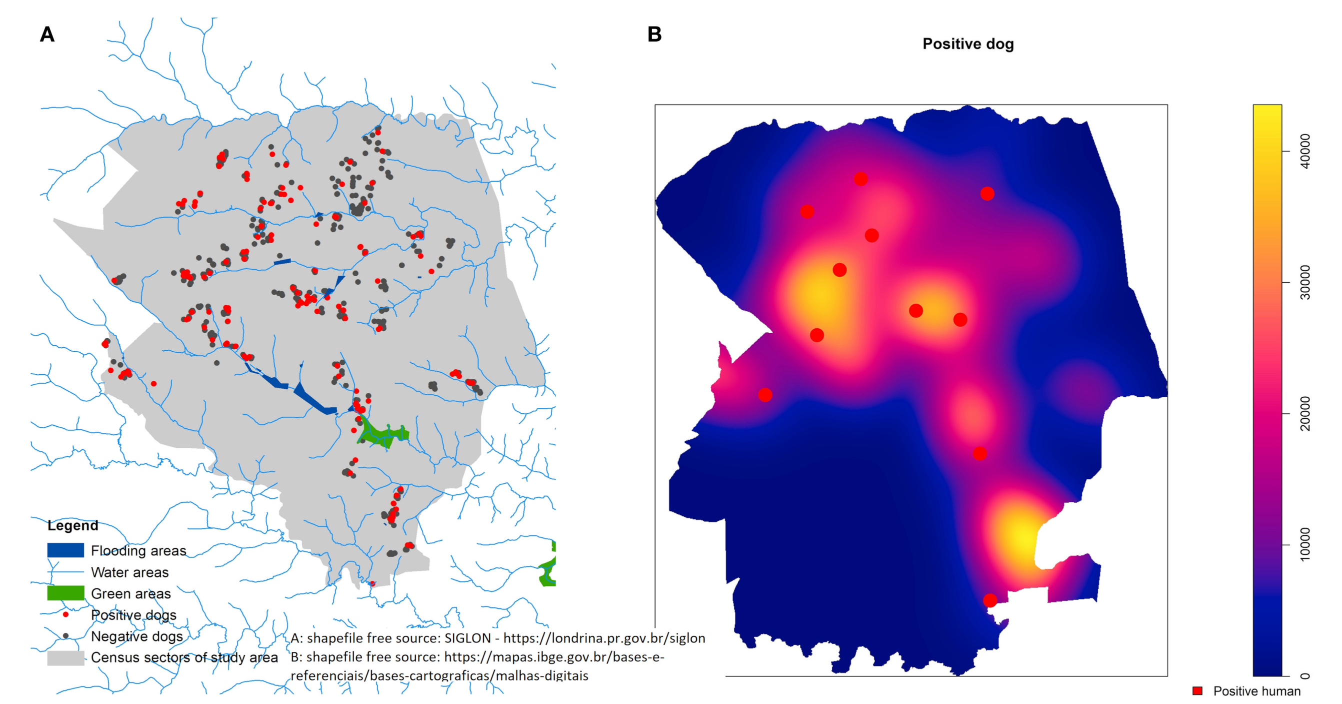

FIGURE 2 | Distribution of positive dogs in flooding, green and water areas **(A)** and kernel density analysis for positive dogs with overlapping positive owner locations **(B)** from July 2015 to July 2016 in the urban area of Londrina, Southern Brazil.

TABLE 2 | Distribution of 597 houses with owners and/or dogs seropositive for *Leptospira*, Canicola serovar, or other serogroups, from July 2015 to July 2016 in the urban area of Londrina, Southern Brazil.

Prevalences	Owners		Dogs		Houses	
	***n*/total (%)**	**95% CI**	***n*/total (%)**	**95% CI**	***n*/total (%)**	**95% CI**
Leptospira	11/597 (1.8)	0.8–3.0	155/729 (21.3)	18.4–24.4	141/565 (25.0)	21.5–28.3
Canicola serogroup	3/597 (0.5)	0.0–1.2	76/729 (10.4)	8.2–12.9	70/565 (12.4)	9.9–15.0
Other serogroups	8/597 (1.3)	0.5–2.3	79/729 (10.8)	8.5–13.2	71/565 (12.6)	9.9–15.8

one dog-only positive household was detected among the total 141/565 (24.95%) positive households (**Table 4**).

For owners, the bivariate analysis of risk factors associated with *Leptospira* antibodies was statistically significant for houses with positive dogs ($p = 0.021$) and houses with nearby forest ($p = 0.043$). The multivariate logistic regression with owners positive for *Leptospira* as the dependent variable did not produce a significant model (**Table 5**).

For dogs, the analysis of risk factors associated with *Leptospira* antibodies was statistically significant for exposed garbage ($p = 0.030$), male sex ($p = 0.003$), presence of equines ($p = 0.001$), presence of opossums ($p = 0.032$), and nearby forests ($p = 0.017$) (**Table 6**). The multivariate logistic regression with dogs positive for *Leptospira* as the dependent variable produced a significant model, with the presence of equines ($p < 0.001$, OR 0.19), female sex ($p = 0.019$, OR 1.67), and exposed garbage ($p = 0.041$, OR 1.51) (**Table 6**).

For households, the analysis of risk factors associated with *Leptospira* antibodies showed statistical significance for open sewage ($p = 0.014$). The multivariate logistic regression with households positive for *Leptospira* as the dependent variable did not produce a significant model (**Table 7**).

As can be seen in **Table 8**, the results demonstrate that intrahousehold conditions, including the backyard situation, rats and family income, have not presented significant effects for dog infection and have failed to explain the probability of a dog infected by *Leptospira* in the household, while parameters related to the neighborhood were significant for dog infection. Dogs from households with unprotected bag discharge in the current study were more likely (and confirmed by logistic model) to be infected by *Leptospira* and serogroup Canicola, while parameters related to the neighborhood were significant for dog infection.

The spatial analysis is shown in **Figures 1, 2** and demonstrated a visual overlap between dog and owner positive cases (**Figure 2B**).

TABLE 3 | Antibody titers for pathogenic *Leptospira* serogroups in positive serum samples of 11 owners and 141 dogs from July 2015 to July 2016 in the urban area of Londrina, Southern Brazil.

		Antibodies titers								
Serogroup	**Serovar**	**100**	**200**	**400**	**800**	**1,600**	**3,200**	**6,400**	**12,800**	**Total (%)**
Owner samples										
Autumnalis	Butembo	04	-	-	-	-	-	-	-	4 (40.0)
Canicola	Canicola	-	01	-	02	-	-	-	-	3 (30.0)
Grippothyhosa	Grippothyphosa	01	01	-	-	-	-	-	-	2 (20.0)
Ballum	Castellonis	01	-	-	-	-	-	-	-	1 (10.0)
Icterohaemorrhagiae	Icterohaemorrhagiae	01	-	-	-	-	-	-	-	1 (10.0)
Total		07	02	-	02	-	-	-	-	10 (100.0)
Dog samples										
Canicola	Canicola	21	21	09	09	10	04	01	01	76 (53.9)
Autumnalis	Butembo	08	05	07	-	01	-	-	-	21 (14.9)
Australis	Bratislava	09	03	-	-	-	-	-	-	12 (8.5)
Grippothyhosa	Grippothyphosa	05	02	01	01	-	-	-	-	09 (6.4)
Icterohaemorrhagiae	Copenhageni	03	03	01	-	-	-	-	-	07 (5.0)
Icterohaemorrhagiae	Icterohaemorrhagiae	03	-	-	-	-	-	-	-	03 (2.1)
Pomona	Pomona	01	05	01	-	-	-	-	-	07 (5.0)
Pyrogenes	Pyrogenes	02	02	-	-	-	01	-	01	06 (4.3)
Total		52	41	19	10	11	05	01	02	141 (100.0)

TABLE 4 | Antibody titers against pathogenic *Leptospira* serogroups in the samples from the 11 households with positive dog owners from July 2015 to July 2016 in the urban area of Londrina, Southern Brazil.

House	**Owners**		**Dogs**		**House**	**Owners**		**Dogs**	
	Serogroup	**Titer**	**Serogroup**	**Titer**		**Titer**	**Titer**	**Serogroup**	**Titer**
A	Canicola	800	Canicola	3,200	G	Autumnalis	100	Canicola	100
B	Canicola	800	Canicola	1,600	H	Autumnalis	100	Negative	-
C	Canicola	200	Canicola	3,200	I	Autumnalis	100	Negative	-
D	Grippotyphosa	100	Autumnalis	200	J	Ballum	100	Negative	-
E	Grippotyphosa	200	Autumnalis	100	K	Icterohaemorrhagiae	100	Negative	-
F	Autumnalis	100	Grippotyphosa	100					

The age analysis showed no significant differences between positive (53.44 ± 18.15 years) and negative (50.87 ± 17.16 years) dog owners ($p = 0.60$). For dogs, the age of positive dogs (5.79 ± 3.96) was significantly higher than that of negative dogs (4.67 ± 3.69) ($p = 0.001$). This variable was included in multilevel regression analysis, but lost significance when with others (**Figure 3**).

The final logistic and spatial regressions were obtained after testing whether the factorial analysis could be applied to transform highly correlated variables in few factors (**Supplementary File**). It was possible to build two factors that together explained 60.2% of the total data variance. The loss of information was relatively low, and synthetic indicators based on factor analysis may have contained the appropriate characteristics. The spatial model, which has used a dependent variable with a variable dummy indicating a positive leptospirosis dog, included two factors (FACT_1 e FACT_2). The factor 1 explaining 38.5% of variance was more correlated to yard variables such as trash, rubble, and low cleaning frequency. The factor 2 explaining 21.7% was more associated to presence and observation of rats. These two factors were also included in the spatial regression analysis besides the control variables described on section "spatial analysis."

After testing 15 matrices of different weights, the results have shown that the residuals were more strongly correlated with the contiguity matrix of the nearest neighbor. Thus, the spatial model has considered this weight matrix and outcome of spatial models were analyzed and presented (**Table 8**).

DISCUSSION

The serological approach to the evaluation of simultaneous and spatial *Leptospira* antibodies in owners and their dogs was accomplished for the first time by the present study, with an

TABLE 5 | Aspatial logistic regression applied to variables with owners seropositivity to leptospirosis.

	Variables		Positive *n* (%)	Negative *n* (%)	Total *N*	OR	95% CI	*p*-value
	Owner							
*	Gender	Female	5 (1.1)	434 (98.9)	439	0.35	0.10-1.23	0.095
		Male^R	5 (3.2)	153 (96.8)	158			
*	Income	< 1 MW	0 (0.0)	147 (100.0)	147	1.02	1.01-1.04	0.058
		> 1 MW^R	10 (2.2)	440 (97.8)	450			
	Accumulated water	Yes	1 (1.3)	78 (98.7)	79	0.73	0.09-5.80	0.610
		No^R	9 (1.7)	509 (98.3)	518			
	Open sewage	Yes	1 (2.5)	39 (97.5)	40	1.56	0.19-12.6	0.503
		No^R	9 (1.6)	548 (98.4)	557			
	Exposed garbage	Yes	7 (1.6)	419 (98.4)	426	0.94	0.24-3.66	0.582
		No^R	3 (1.8)	168 (98.2)	171			
	Wasteland	Yes	6 (2.0)	299 (98.0)	305	1.44	0.40-5.17	0.403
		No^R	4 (1.4)	288 (98.6)	292			
*	Bathroom outside	Yes	4 (3.5)	111 (96.5)	115	2.85	0.79-10.26	0.108
		No^R	6 (1.2)	474 (98.8)	480			
*	Presence of rats	Yes	5 (1.1)	446 (98.9)	451	0.32	0.09-1.11	0.070
		No^R	5 (3.4)	141 (96.6)	146			
**	House with postive dog	Yes	6 (3.9)	146 (96.1)	152	4.52	1.26-16.24	0.021
		No^R	4 (0.9)	440 (99.1)	444			
	Dirty backyard	Yes	4 (1.7)	234 (98.3)	238	1.01	0.28-3.60	0.616
		No^R	6 (1.7)	353 (98.3)	359			
*	Job outside	Yes	1 (0.5)	210 (99.5)	211	0.20	0.03-1.58	0.080
		No^R	9 (2.3)	375 (97.7)	384			
**	Nearby forest	Yes	1 (0.4)	240 (99.6)	241	0.16	0.02-1.28	0.043
		No^R	9 (2.5)	347 (97.5)	356			
	Icterus as clinical sign	Yes	1 (2.0)	48 (98.0)	49	1.33	0.16-10.82	0.560
		No^R	9 (1.5)	509 (98.5)	517			

Bivariate and multivariate logistic regression analysis of dog owners positive for Leptospira from July 2015 to July 2016 in the urban area of Londrina, Southern Brazil.
**Variables included in the logistic models.*
^{R}*Reference category.*
***Variables with $p < 0.05$.*
There was no significant multiple logistic model.
MW, minimum wage.

overall human:dog leptospirosis positivity ratio of 1:11.55 and an owner seroprevalence that was significantly lower than that of their dogs. Using a similar comprehensive approach, our research group previously demonstrated the opposite pattern for toxoplasmosis, with a human:dog ratio of 2.55:1, an owner seroprevalence significantly higher than that of their dogs, with canine seroprevalence directly associated with having more dogs and a dirty backyard, and with spatial differences between owner and dog exposures (39).

Serological surveys on canine leptospirosis throughout Latin America have shown wide-ranging prevalence rates, varying from 4.9 to 72.0% depending on country, region, dog population and historical endemic level (40). Prevalence studies have varied from 41/335 (12.23%) positive stray dogs in northern Brazil (40), 163/1,233 (13.21%) positive domiciled dogs in a poor flooding area in eastern Brazil (23), 35/175 (20.00%) positive culled stray dogs in western Brazil (18), 132/653 (20.21%) positive owned dogs in an urban area near Londrina (19), 7/33 (21.21%) positive abandoned stray dogs on the Londrina State University campus (30), 51/236 (21.61%) positive owned dogs from a University neutering program in northern Brazil (31), and 33/228 (14.4%) and 35/90 (38.9%) positive dogs in the same city of the capital metropolitan area in an eastern Brazilian (41) state.

The seroprevalence of 155/729 (21.26%) positive dogs in the current study was within previous findings for Londrina city (20.21, 21.21, and 21.61%), with surprisingly non-significant differences in prevalence despite differences in the dogs with regard to street access and owner care (18, 19, 30, 31). Thus, the current study may offer a comprehensive and non-biased serologic survey of domiciled dogs throughout the urban city area by randomly including dogs and owners from a representative household distribution.

The Brazilian Ministry of Health has established a unified mandatory notification system for suspected human leptospirosis cases, which provides epidemiological information on endemicity nationwide. Despite subpar notification rates due to lack of diagnosis and mild or non-attended cases, Parana

TABLE 6 | Aspatial logistic regression applied to variables with dogs seropositivity to leptospirosis.

	Variables		Positive *n* (%)	Negative *n* (%)	Total *N*	OR	95% CI	*p*- value
	Dogs							
	Income	≤ 1 MW	37 (21.9)	132 (78.1)	169	1.05	0.69–1.59	0.447
		> 1 MW[R]	118 (21.1)	442 (78.9)	560			
*	Accumulated water	Yes	25 (26.0)	71 (74.0)	96	1.36	0.83–2.24	0.137
		No[R]	130 (20.5)	503 (79.5)	633			
	Open sewage	Yes	12 (21.1)	45 (78.9)	57	0.99	0.51–1.91	0.562
		No[R]	143 (21.3)	529 (78.7)	672			
**	Exposed garbage	Yes	104 (19.4)	431 (80.6)	535	0.68	0.46–0.99	0.030
		No[R]	51 (26.3)	143 (73.7)	194			
	Wasteland	Yes	80 (21.3)	296 (78.7)	376	1.00	0.70–1.43	0.532
		No[R]	75 (21.2)	278 (78.8)	353			
**	Sex	Female	71 (17.4)	336 (82.6)	407	1.49	1.13–1.97	0.003
		Male[R]	84 (26.1)	238 (73.9)	322			
	Bathroom outside	Yes	28 (20.7)	107 (79.3)	135	0.97	0.61–1.53	0.493
		No[R]	126 (21.3)	465 (78.7)	591			
	Presence of rats	Yes	116 (20.6)	446 (79.4)	562	0.85	0.56–1.29	0.258
		No[R]	39 (23.4)	128 (76.6)	167			
*	Street Access	Yes	93 (24.0)	294 (76.0)	387	1.43	0.99–2.05	0.052
		No[R]	62 (18.1)	280 (81.9)	342			
	Hunting Habit	Yes	69 (21.6)	250 (78.4)	319	1.04	0.73–1.49	0.830
		No[R]	86 (21.0)	324 (79.0)	410			
**	Presence of equines	Yes	15 (60.0)	10 (40.0)	25	6.04	2.66–13.74	0.001
		No[R]	140 (19.9)	564 (80.1)	704			
*	Presence of bovines	Yes	2 (66.7)	1 (33.3)	3	7.49	0.67–83.15	0.116
		No[R]	153 (21.1)	573 (78.9)	726			
**	Presence of opossums	Yes	3 (75.0)	1 (25.0)	4	11.31	1.17–109.49	0.032
		No[R]	152 (21.0)	573 (79.0)	725			
***	Presence of other positive dogs	Yes	0 (0.0)	50 (100.0)	50	-	-	-
		No[R]	155 (22.8)	524 (77.7)	679			
*	Clinical sign: vomit and/or diarrhea	Yes	21 (17.1)	102 (82.9)	123	0.73	0.44–1.20	0.129
		No[R]	134 (22.1)	472 (77.9)	606			
	Dirty backyard	Yes	62 (20.3)	244 (79.7)	306	0.90	0.63–1.29	0.320
		No[R]	93 (22.0)	330 (78.0)	423			
**	Nearby forest	Yes	33 (29.5)	79 (70.5)	112	1.69	1.08–2.66	0.017
		No[R]	122 (19.8)	495 (80.2)	617			
	Contact with other domestic animal	Yes	124 (21.0)	467 (79.0)	591	0.92	0.59–1.43	0.390
		No[R]	31 (22.5)	107 (77.5)	138			
	Presence of dogs	Yes	115 (20.9)	434 (79.1)	549	0.93	0.62–1.39	0.395
		No[R]	40 (22.2)	140 (77.8)	180			
	Clinical sign: weight loss	Yes	16 (23.9)	51 (76.1)	67	1.18	0.65–2.13	0.583
		No[R]	139 (21.0)	523 (79.0)	662			

Final logistic model	Adjusted-OR	95 CI adjusted-OR	*p*-value (Wald test)
Presence of equines	0.19	0.08–0.43	<0.001
Sex (female)	1.67	1.17–2.23	0.019
Exposed garbage	1.51	1.02–2.23	0.041

Bivariate and multivariate logistic regression analysis of dogs positive for Leptospira from July 2015 to July 2016 in the urban area of Londrina, Southern Brazil.
There was no significant interactions between co-variates of the final model.
**Variables included in the logistic models.*
***There was no sufficient expose and no expose to proceed the analysis.*
****There was no sufficient animals to calculate.*
MW, minimum wage.
[R]Reference category.

TABLE 7 | Aspatial logistic regression applied to variables with households positivity to leptospirosis.

	Variables		Positive *n* (%)	Negative *n* (%)	Total *N*	OR	95% CI	*p*-value
	House							
	Income	≤ 1 MS	40 (27.8)	104 (72.2)	144	1.22	0.79–1.87	0.212
		> 1 MS[R]	101 (24.0)	320 (76.0)	421			
	Accumulated water	Yes	17 (22.1)	60 (77.9)	77	0.83	0.47–1.47	0.318
		No[R]	124 (25.4)	364 (74.6)	488			
**	Open sewage	Yes	4 (10.0)	36 (90.0)	40	0.32	0.11–0.90	0.014
		No[R]	137 (26.1)	388 (73.9)	525			
	Exposed garbage	Yes	103 (25.1)	308 (74.9)	411	1.02	0.67–1.57	0.509
		No[R]	38 (24.7)	116 (75.3)	154			
*	Wasteland	Yes	80 (26.7)	220 (73.3)	300	1.22	0.83–1.79	0.183
		No[R]	61 (23.0)	204 (77.0)	265			
	Bathroom outside	Yes	25 (22.9)	84 (77.1)	109	0.87	0.53–1.42	0.333
		No[R]	116 (25.6)	338 (74.4)	454			
*	Presence of rats	Yes	98 (23.1)	327 (76.9)	425	0.68	0.44–1.03	0.069
		No[R]	43 (30.7)	97 (69.3)	140			
	Dirty backyard	Yes	58 (25.1)	173 (74.9)	231	1.01	0.69–1.49	0.944
		No[R]	83 (24.9)	251 (75.1)	334			

Bivariate and multivariate logistic regression analysis of households positive for Leptospira from July 2015 to July 2016 in the urban area of Londrina, Southern Brazil.
**Variables included in the logistic models.*
***Variables with $p < 0.05$.*
MW, minimum wage.
There was no significant logistic model.
[R]Reference category.

was ranked fifth out of 26 Brazilian states and the national capital in 2015, with 362/3,257 (11.11%) of the total human confirmed cases, of which 18/362 (4.97%) cases and 07/18 (38.88%) deaths were reported in Londrina; a similar pattern with 05/14 (35.71%) deaths was observed in 2016 (42). The human seroprevalence results of 11/597 (1.84%) in the current study may corroborate the only two human studies from the same region, which have found 25/207 (12.1%) human cases near (33 km) Londrina city (33) and 2/157 (1.27%) cases among veterinary students in the northwestern Parana State (43). Despite the contact with positive dogs, the frequency of human infection and infection risk have been relatively low and the simultaneous positive serology of owners and dogs has provided a comparative and statistically significant human:dog ratio of 2.55:1, which may be used as a comparative parameter of local exposure to *Leptospira*.

Differences in human and dog serology may reflect distinct infection patterns according to host species. While pathogenic *Leptospira* have mostly caused human acute disease by accidental host infection without renal carrier status (1), dogs present different degrees of acute or chronic disease and occasional colonization of the renal tubules, leading to a long-term shedding and reservoir state (3). In such a scenario, a higher prevalence of seropositive dogs in a specific area may indicate spirochete circulation among animal populations, occasionally leading to human infection (44). Molecular investigations in different hosts have shown that the genetic machinery of serogroup Canicola may lead to a similar infection potential in human beings (45), pigs and dogs (46).

The present study has shown that seropositive domiciled dogs may indicate an intra- and peridomiciliar risk environment because they were exposed daily to the outdoor area near the household environment, returning at night, exponentially increasing contact and potentiate owner infection. Although eliminating outside may not directly characterize an associated risk factor for leptospirosis in dogs, the likelihood of rats in the backyard may increase under such conditions.

Although rodents have been considered the main urban hosts for leptospiral harboring and maintenance, particularly in slums (16, 47), dogs and other animal species may be implicated in the local epidemiology of human disease (48). Leptospiral genotyping in human and rat infections in Seychelles, which has one of the highest worldwide incidence rates, has proposed other animal reservoirs (49). In addition, a space-time association has been established between domestic animal and human incidence, with the epidemiology of animal infection being an associated risk for local human infection (50).

Although the present study has focused on concomitant seroprevalence and associated risk factors for leptospirosis seropositivity, individual analysis of serogroups, particularly Canicola, may provide important information since the role of dogs were surveyed as potential reservoirs and as susceptible species. Such a double role of dogs in the leptospiral life cycle may lead to long periods of infection and may explain the higher prevalence of serogroup Canicola in 3/11 (27.27%) owners and 76/155 (49.03%) dogs. However, detection of other serogroups in 8/11 (72.72%) owners and 65/155 (41.94%) dogs may indicate the

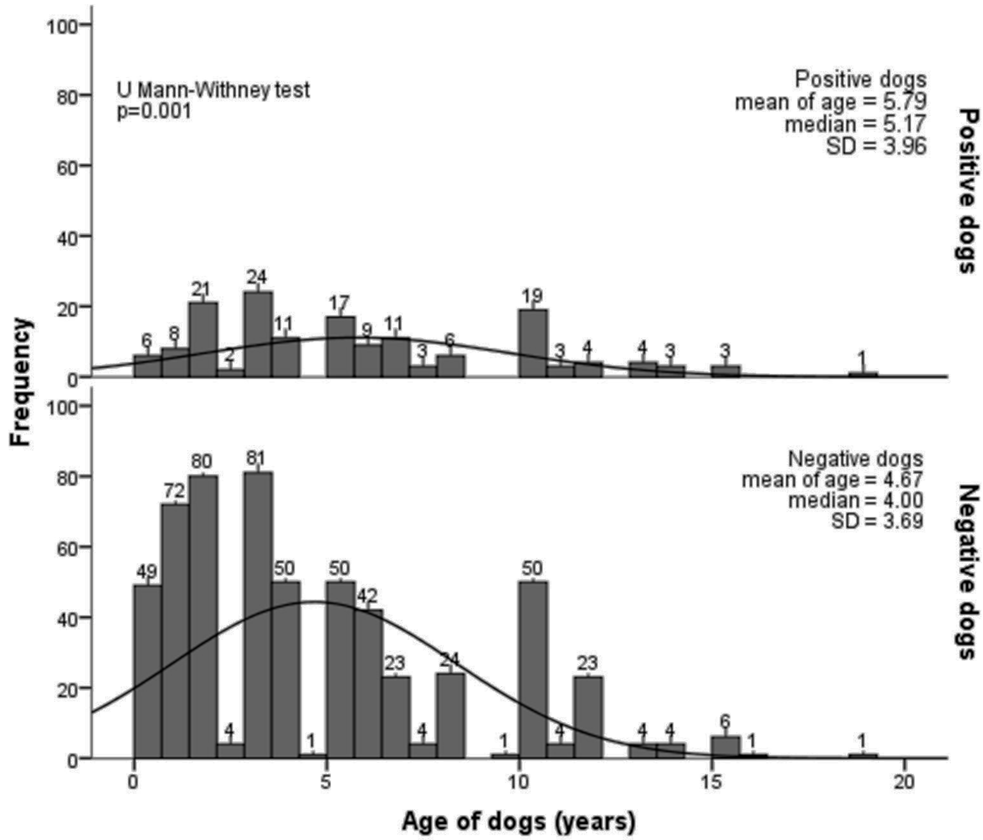

FIGURE 3 | Histogram of age for positive and negative dogs for *Leptospira* from July 2015 to July 2016 in the urban area of Londrina, Southern Brazil.

presence of other environmental reservoirs that may be a source of infection for both human beings and dogs.

A previous survey of human and animal leptospirosis in Southern Brazil (51) found Canicola to be the most prevalent serogroup in dogs with 329/1,176 (27.96%) positive for the Tande strain, 266/1,176 (22.60%) positive for the Kito strain and 216/1176 (18.34%) positive for the Hond Utrecht IV strain; Autumnalis was the most prevalent human serogroup, with 195/997 (19.41%) seropositive humans. A previous study similarly found low detection of the common worldwide human serogroup Icterohaemorrhagiae (Copenhageni and Icterohaemorrhagiae) among human beings and dogs (46, 52).

Early studies have molecularly detected shedding of Leptospira in the urine of asymptomatic dogs with different serological titers (53, 54). In addition, MAT may not differentiate among infection, vaccination, and maternal antibodies (55), and puppies younger than 6 months and dogs vaccinated dogs <6 months prior were excluded from the descriptive statistical analyses. Hence, leptospiruria in any given dog may have played a role in environmental contamination in the present study. In addition, due to the lack of paired samples, particularly from seropositive titers, no disease could be confirmed based on a 4-fold increase in titer between paired sera (56). For dogs, parameters defining infection have not been fully established. Thus, although human titers ≥ 400 for one or more serogroups can be interpreted as a present or recent infection, no extrapolation has been made for dogs.

Despite it was not the most frequent, the high frequency of serogroup Autumnalis and the decreased frequency of serogroup Icterohaemorrhagiae have corroborated previous studies; this pattern may be associated with long-term canine vaccination and may have demonstrated a distinct pattern of leptospirosis, which may suggest urban environmental contamination (57). Although not the focus of the present study, rodents, and other local animal species (opossums, agoutis, capybaras) should be further surveyed, if possible, to fully establish their role regarding each leptospiral serogroup. Such studies should be used as a basis for future local public health actions for leptospirosis control and prevention.

Considering that human leptospirosis may cause non-specific febrile disease and self-remission within a week after onset (58), the three owners with titers for serogroup Canicola of 1:200, 1:200, and 1:800 may have experienced mild infection since no clinical signs were mentioned at the time of blood samplings. Since the dogs of these owners also presented high titers, with 1:3,200, 1:1,600, and 1:3,200 for serogroup Canicola, respectively, the same exposure source in the intra-domiciliary infection from dog to its owner should be considered. The

TABLE 8 | Spatial multivariate logistic regression.

	Multivariate logistic	MV (SAR)[b]	MV (SEM)[c]	GMM (SAR)[d]
Dependent variable: dogs positive to *Leptospira*				
Presence of a positive human	1.48***	0.24**	0.26***	0.23**
	(0.50)	(0.10)	(0.10)	(0.12)
Vaccine	0.01	−0.09*	−0.09**	−0.09**
	(0.07)	(0.05)	(0.05)	(0.04)
Street Access	0.09	0.10**	0.11***	0.10**
	(0.10)	(0.04)	(0.04)	(0.04)
Income2	−0.12	−0.01	0.00	−0.01
	(0.23)	(0.04)	(0.04)	(0.04)
Income3	−0.11	0.03	0.04	0.03
	(0.27)	(0.04)	(0.05)	(0.04)
Presence of dogs	−0.06	−0.06	−0.05	−0.06
	(0.06)	(0.04)	(0.04)	(0.04)
More than one dog in the house	−0.06	0.00	0.01	0.00
	(0.26)	(0.01)	(0.01)	(0.01)
FACT_1	−0.01	−0.08	−0.07	−0.07
	(0.22)	(0.05)	(0.05)	(0.05)
FACT_2	−0.01	−0.07	−0.06	−0.06
	(0.33)	(0.05)	(0.05)	(0.05)
Households	0.02	0.01	0.01	0.01
	(0.05)	(0.01)	(0.01)	(0.01)
Constant	−1.29***	0.19***	0.22***	0.15***
	(0.32)	(0.06)	(0.06)	(0.07)
Lambda		0.02***		0.05***
		(0.01)		(0.02)
Rho			0.03***	
			(0.01)	
AIC[a]	761	757	751	-
BIC	811	822	816	-

[a]Akaike's information.
[b]Maximum Likelihood Estimation.
[c]Maximum Likelihood Estimation.
[d]Estimation by the Generalized Method of Moments because of the endogeneity of the spatially lagged dependent variable.
****Variables with $p < 0.01$.*
***Variables with $p < 0.05$.*
**Variables with $p < 0.10$.*

current analysis detected a statistically significant association between the presence of a reactive dog in the household and a greater likelihood of infection by *Leptospira* in its owner. Further studies should focus on the serological and molecular assessment of dogs, dog owners, rats, and the environment in the same household to fully establish the role of each on the *Leptospira* life cycle.

The association between households with a seropositive owner or dog and risk of infection may also suggest the intra-domiciliary influence on infection for both owners and dogs. Moreover, proximity among households with positive owners from households with positive dogs has suggested the likelihood of peri-domiciliary infection. Unexpectedly, no clusters were observed in the studied area, and peri-domiciliary standing water following rain, green areas and water areas were not associated with the likelihood of infection; these factors have been previously shown to favor the survival of pathogenic *Leptospira* (59).

In the present study, despite the impossibility of multivariate logistic model calculation in owners due to the low prevalence of 11/597 (1.84%) positive individuals, the univariate analysis showed an association between visiting woody areas and *Leptospira* infection; however, there was no association between infection and having these areas near the residences. Hence, even non-endemic and no-flooding areas may be exposed to infection due to other environmental causes. In environments of high infection risk due to rodent infestation and flooding, a decrease in human leptospirosis cases may be reached by efforts in community improvements, particularly at the household and individual levels (60). Likewise, dogs from households with unprotected bag discharge were more likely (and confirmed by logistic model) to be infected by *Leptospira* and serogroup Canicola in the current study. Exposed garbage outside of the households may have attracted rats, peridomestic and wild species and also stray dogs nearby and contributed to the environmental contamination with the *Leptospira* in the surrounding microenvironments; a similar finding was previously observed in a case-control outbreak of human leptospirosis in which the presence of seroreactive dogs with leptospiruria in an owner-case household may have suggested high environmental contamination that caused a sequence of direct transmission (61).

The association of female dogs with anti-*Leptospira* antibodies has not been corroborated by previous studies, which have shown males with higher prevalence than females, probably due to territorial demarcation (62). However, the prior study was performed in stray dogs, and different degrees of street access may impact infection exposure. Likewise, the higher mean and median age of positive dogs compared with negative dogs may reflect a longer exposure time to potential environmental sources of infection for both males and females.

In the present study, the peridomiciliary presence of horses influenced the prevalence of dogs seroreactive for *Leptospira*. Interestingly, 214/320 (66.88%) horses used for carrying recycling material in the same urban area of the present study have shown seropositivity for leptospirosis (63), with 47/62 (75.80%) positive horses in a similar urban setting nearby, but there was no association with reactive dogs. These studies have suggested that seropositivity may be associated with horse permanence in low sanitary areas with the presence of rodents, similar to dog exposure and the likelihood of infection. However, as *Leptospira* strains have been isolated from mare urine (64), the possibility of infection in dogs from horse urine may not be ruled out and should be further investigated (65). Besides the relationship between environmental factors can be influence on this association, this factor was tested and not demonstrate significant results in the present study.

The results of this study were produced in a bivariate analysis. In addition, identification of which variables were significant was also relevant to explaining the dog leptospirosis prevalence in a multivariate context. Thus, four investigative econometric models have been estimated, including eventual neighborhood effects, meaning whether a dog has a higher likelihood of infection when the next-door neighbor dog is seropositive.

In addition, the internal conditions of the house do not have significant effects on animal infection. However, the parameters for the neighborhood were significant (Rho). Special attention should be given to the SAR and SEM models since eventual endogeneity problems are considered, and they use spatially lagged exogenous variables as instruments. These models may suggest that, if the neighbors' dogs have been infected, there would be an increased likelihood of infection of an animal in a specific household. Therefore, once again, the environment conditions, in addition to the residence, may be crucial to an increased probability of dog leptospirosis.

Only three variables were relevant in the explanation of the dependent variable, considering a 10% significance level. These results were interestingly similar to those observed in the logit model when not considering space. Dogs that have been vaccinated in the last 6 months are less likely to be infected, and if there was any individual with leptospirosis, the likelihood of an infected dog would be higher. The significance of the street variable suggests that the free-range dogs may be more likely to have a *Leptospira* infection than those who were bred indoors or were semidomiciled and finally, if a residence has an individual reactive to *Leptospira*, there is a greater probability that there will be an infected dog in the house.

The previous studies focused on the zoonotic infection with association of companion dog and owners has only been suggested in the presence of flooding areas as during an outbreak of hemorrhagic fever in late 1990's in Nicaragua (61) and after detection of *L. interrogans* in environmental water samples in Thailand (66), which has not occurred in the present study. Such findings may suggest a direct "flooding free" contact model involving a mammal triangle and cross-infection of owners and their dogs. The World Health Organization (WHO) authorities have already been alerted to the potential public health threat due to the increasing human:animal bond, especially due to zoonotic transmission suggesting a new global holistic and unified approach to One Health (67). Based on the comparative comprehensive study herein, strategies for control measures against leptospirosis should include pet vaccination, restriction of street access, and careful urine manipulation.

CONCLUSION

Finally, the present study has shown a higher risk of owner leptospirosis associated with their own reactive dogs, particularly for serogroup Canicola, contributing to a better understanding of leptospirosis cross-species infection. In addition, simultaneous seropositivity in two owners living in the same household as their dogs strongly suggests an intradomicile-transmitted infection, with a direct or indirect role played by their owned dogs.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by National Human Ethics Research Committee (protocol number 1,025,861/2014) at Londrina State University, Southern Brazil. The patients/participants provided their written informed consent to participate in this study. The animal study was reviewed and approved by Animal Use Ethics Committee (protocol number 181/2014), at Londrina State University, Southern Brazil. Written informed consent was obtained from the owners for the participation of their animals in this study.

AUTHOR CONTRIBUTIONS

AB contributed to conception, design of the study, and wrote sections of the manuscript. TM, AM, MR, IS, and TL contributed to organized the database. RF, CM, AB, and RR performed the statistical analysis and wrote sections of the manuscript. RM-B, JG, FC, EW, AK, and IN wrote sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

FUNDING

CAPES/CNPq have provided only funding for Dr. Benitez costs, which included fellowship and travel grants for meeting presentations.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fvets.2020.580400/full#supplementary-material

REFERENCES

1. Ko AI, Goarant C, Picardeu M. *Leptospira*: the dawn of the molecular genetics era for an emerging zoonotic pathogen. *Nat Rev Microbiol*. (2009) 736–47. doi: 10.1038/nrmicro2208
2. Fraga TR, Carvalho E, Isaac L, Barbosa AS. *Leptospira* and leptospirosis. *Mol Med Microbiol*. (2015) 4:1973–90. doi: 10.1016/B978-0-12-397169-2.00107-4
3. Levett PN, Branch SL, Whittington CA, Edwards CN, Paxron H. Two methods for rapid serological diagnosis of acute leptospirosis. *Clin Vac Immunol*. (2001) 8:2–5. doi: 10.1128/CDLI.8.2.349-351.2001

4. Picardeau M. Diagnosis and epidemiology of leptospirosis. *Med Malad Infect*. (2013) 43:1–9. doi: 10.1016/j.medmal.2012.11.005
5. Faine S, Adler B, Bolin C, Perolat P. *Leptospira and leptospirosis*, *2nd edn*. Melbourne, VIC: MediSci (1999).
6. Adler B, Lo M, Seemann T, Murray GL. Pathogenesis of leptospirosis: the influence of genomics. *Vet Microbiol*. (2011) 153:73–81. doi: 10.1016/j.vetmic.2011.02.055
7. Costa F, Martinez-Silveira M, Hagan JE, Hartskeerl RA, Reis MG, Ko AI. Surveillance for leptospirosis in the Americas, 1996–2005: a review of data from ministries of health. *Rev Panam Salud Públ*. (2012) 32:169–77. doi: 10.1590/S1020-49892012000900001
8. Costa F, Hagan JE, Calcagno J, Kane M, Togerson P, Martinez-Silveira MS, et al. Global morbidity and mortality of leptospirosis: a systematic review. *PLoS Negl Trop Dis*. (2015) 9:e0003898. doi: 10.1371/journal.pntd.0003898
9. Pappas G, Papadimitriou P, Siozopoulou V, Christou L, Akritidis N. The globalization of leptospirosis: worldwide incidence trends. *Int J Infect Dis*. (2008) 12:351–7. doi: 10.1016/j.ijid.2007.09.011
10. Maciel EAP, de Carvalho ALF, Nascimento SF, Matos RB, Gouveia EL, Reis MG, et al. Household transmission of *Leptospira* infection in urban slum communities. *PLoS Negl Trop Dis*. (2008) 2:e154. doi: 10.1371/journal.pntd.0000154
11. Jesus MS de, Silva LA, Lima KM da S, Fernandes OCC. Cases distribution of leptospirosis in City of Manaus, State of Amazonas, Brazil, 2000–2010. *Rev Soc Bras Med Trop*. (2012) 45:713–6. doi: 10.1590/S0037-86822012000600011
12. Silva LA, Lima KM da S, Fernandes OCC, Balassiano IT, Avelar KES, Jesus MS. Seroprevalence of and risk factors for leptospirosis in the city of Manaus, State of Amazonas, Brazil. *Rev Soc Bras Med Trop*. (2016) 49:628–31. doi: 10.1590/0037-8682-0115-2016
13. Sánchez-Montes S, Espinosa-Martínez DV, Ríoz-Muñoz CA, Berzunza-Cruz M, Becker I. Leptospirosis in Mexico: epidemiology and potential distribution of human cases. *PLoS ONE*. (2015) 10:e0133720. doi: 10.1371/journal.pone.0133720
14. Schneider MC, Najera P, Pereira MM, Machado G, dos Anjos CB, Rodrigues RO, et al. Leptospirosis in Rio Grande do Sul, Brazil: an ecosystem approach in the animal-human interface. *PLoS Negl Trop Dis*. (2015) 9:e0004095. doi: 10.1371/journal.pntd.0004095
15. Reis RB, Ribeiro GS, Felzemburg RDM, Santana FS, Mohr S, Melendez AXTO, et al. Impact of environment and social gradient on *Leptospira* infection in urban slums. *PLoS Negl Trop Dis*. (2008) 2:e0000228. doi: 10.1371/journal.pntd.0000228
16. Cosson JF, Picardeau M, Mielcarek M, Tatard C, Chaval Y, Suputtamongkol Y, et al. Epidemiology of *Leptospira* transmitted by rodents in Southeast Asia. *PLoS Negl Trop Dis*. (2014) 8:e0002901. doi: 10.1371/journal.pntd.0002902
17. Hagan JE, Moraga P, Costa F, Capian N, Ribeiro GS, Wunder Jr EA, et al. Spatiotemporal determinants of urban leptospirosis transmission: four-year prospective cohort study of slum residents in Brazil. *PLoS Negl Trop Dis*. (2016) 10:e0004275. doi: 10.1371/journal.pntd.0004275
18. Dreer MK de P, Gonçalves DD, Caetano ICS, Gerônimo E, Menegas PH, Bergo D, et al. Toxoplasmosis, leptospirosis and brucellosis in stray dogs housed at the shelter in Umuarama municipality, Paraná, *Braz. J Venom Anim Toxins Incl Trop Dis*. (2013) 19:23. doi: 10.1186/1678-9199-19-23
19. Benitez do Nascimento A, Gonçalves DD, Freire EL, Rodrigues WB, Souza VRA, Barbara JCA, et al. Seroepidemiology of leptospirosis in pet dogs in the urban area of the municipality of Jataizinho, Paraná. *Semin Ciênc Agrar*. (2012) 33:3201–10. doi: 10.5433/1679-0359.2012v33Supl 2p3201
20. Sarkar U, Nascimento SF, Barbosa R, Martins R, Nuevo H, Kalofonos I, et al. Population-based case-control investigation of risk factors for leptospirosis during an urban epidemic. *Am J Trop Med Hyg*. (2002) 66:605–10. doi: 10.4269/ajtmh.2002.66.605
21. Costa F, Ribeiro GS, Felzemburgh RDM, Santos N, Reis RB, Santos AC, et al. Influence of household rat infestation on *Leptospira* transmission in the urban slum environment. *PLoS Negl Trop Dis*. (2014) 8:e3338. doi: 10.1371/journal.pntd.0003338
22. Martins G, Penna B, Lilembaum W. The dog in the transmission of human leptospirosis under tropical conditions: victim or villain? *Epidemiol Infect*. (2012) 140:207–9. doi: 10.1017/S09502688110 00276
23. Morikawa VM, Bier D. Pellizzaro M, Ulmann LS, Paploski IAD, Kikut M, et al. Seroprevalence and seroincidence of *Leptospira* infection in dogs during a 1-year period in an endemic urban area in Southern Brazil. *Rev Soc Bras Med Trop*. (2015) 48:50–5. doi: 10.1590/0037-8682-0213-2014
24. WHO. *Report of the First Meeting of the Leptospirosis Burden Epidemiology Reference Group*. Geneva: WHO Press (2001).
25. WHO. *The One Health Iniciative*. (2014). Available online at: http://www.onehealthinitiative.com/ (accessed September 20, 2017).
26. Hartskeerl RA, Collares-Pereira M, Ellis WA. Emergence, control and re-emerging leptospirosis: dynamics of infection in the changing world. *Clin Microbiol Infect*. (2011) 17:494–501. doi: 10.1111/j.1469-0691.2011.03474.x
27. IBGE. *Cidades*. Instituto Brasileiro de Geografia e Estatística (2015). Available online at: https://cidades.ibge.gov.br/brasil/pr/londrina/panorama (accessed September 20, 2017).
28. IBGE. *Universo de População e Domicílio*. Instituto Brasileiro de Geografia e Estatística. (2015). Available online at: https://cidades.ibge.gov.br/brasil/pr/londrina/pesquisa/23/24304?detalhes=true&localidade1=410690 (accessed September 21, 2017).
29. Ayres M, Ayres JR, Ayres DL, Santos AS. *BioEstat 3.0: Aplicações estatística nas áreas das ciências biológicas e médicas*. Belém, PA:Sociedade Civil de Mamirauá. (2003).
30. Benitez A, Rodrigues GG, Gonçalves DD, Burke JC, Alves LA, Müller EE, et al. Leptospirose em cães errantes encontrados em campus universitário: avaliação sorológica e exame direto da urina. *Semin Ciênc Agrar*. (2010) 31:191–6. doi: 10.5433/1679-0359.2010v31n1p191
31. Caldart ET, Constantino C, Pasquali AKS, Benitez NA, Hamada FN, Dias RCF, et al. Zoonosis in dogs and cats attended by the Birth Control Project: *Toxoplasma gondii*, *Leishmania* spp. and *Leptospira* spp., serodiagnosis and epidemiology. *Semin Ciênc Agrar*. (2015) 36:253–66. doi: 10.5433/1679-0359.2015v36n1p253
32. Blanco RM, dos Santos LF, Galloway RL, Romero EC. Is the microagglutination test (MAT) good for predicting the infecting serogroup for leptospirosis in Brazil? *Comp Immunol Microbiol Infect Dis*. (2016) 44:34–6. doi: 10.1016/j.cimid.2015.12.003
33. Gonçalves DD, Benitez A, Lopes-Mori FMR, Alves LA, Freire RL, et al. Zoonoses in humans from small rural properties in Jataizinho, Parana, Brazil. *Braz J Microbiol*. (2013) 44:125–31. doi: 10.1590/S1517-8382201300 5000011
34. R Core Team. *R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing*. Vienna (2017). Available online at: http//www.R-project.org
35. Chongsuvivatwong V. *EpiDisplay: epidemiological data display package. R package version 3.2.0*. (2015). Available online at: https://CRAN.R-project.org/package=epiDisplay (accessed September 21, 2017).
36. Baddeley A, Turner R, Mateu J, Bevan A. Hybrids of gibbs point process models and their implementation. *J Stat Softw*. (2013) 55:1–43. doi: 10.18637/jss.v055.i11
37. Edwards A. Computational estimation for numeracy. *Educ Stud Math*. (1984) 15:59–73. doi: 10.1007/BF00380439
38. Anselin L, Bera A. Spatial dependence in linear regression models with an introduction to Spatial Econometrics. In: Ullah A, Giles DE, editors. *Handbook of Applied Economic Statistics*. New York, NY: Marcel Dekker. (1998). p. 237–89.
39. Benitez A do N, Martins FDC, Mareze M, Santos NJR, Ferreira FP, Martins CM, et al. Spatial and simultaneous representative seroprevalence of anti-*Toxoplasma gondii* antibodies in owners and their domiciled dogs in a major city of Southern Brazil. *PLoS ONE*. (2017) 12:e0180906. doi: 10.1371/journal.pone.0180906
40. Pinto PS, Libonati H, Lilembaum W. A systematic review of leptospirosis on dogs, pigs, and horses in Latin America *Trop An Health Product*. (2017) 49:231–8. doi: 10.1007/s11250-016-1201-8
41. Fonzar UJV, Langoni H. Geographic analysis on the occurrence of human and canine leptospirosis in the city of Maringá, state of Paraná, Brazil. *Rev Soc Bras Med Trop*. (2012) 45:100–5. doi: 10.1590/S0037-86822012000100019
42. Martins CM, Barros C da, Galindo AM, Kikuti M, Ullman LS, Pampuch RS, et al. Incidence of canine leptospirosis in the metropolitan area of Curitiba, State of Paraná, Southern Brazil. *Rev Soc Bras Med Trop*. (2013) 46:772–5. doi: 10.1590/0037-8682-1665-2013

43. DATASUS. (2016). Available online at: http://tabnet.datasus.gov.br/cgi/tabcgi.exe?sinannet/cnv/leptobr.def (accessed September 21, 2017).
44. Clazer M, Rodrigues GV, Ferreira BPM, Zaniolo MM, Corrêa NAB, Fortes MS, et al. Toxoplasmosis, leptospirosis, and brucellosis seroepidemiology in veterinary medical students and their relation with unique health. *Semin Ciênc Agrar*. (2017) 38:1347–60. doi: 10.5433/1679-0359.2017v38n3p1347
45. Delaude A, Rodriguez-Campos S, Dreyfys A, Counotte MJ, Francey T, Schweighauser A, et al. Canine leptospirosis in Switzerland—a prospective cross-sectional study examining seroprevalence, risk factors and urinary shedding of pathogenic leptospires. *Prev Vet Med*. (2017) 141:48–60. doi: 10.1016/j.prevetmed.2017.04.008
46. Zhu WN, Huang LL, Zeng LB. Isolation and characterization of two novel plasmids from pathogenic *Leptospira interrogans* serogroup canicola serovar canicola strain Gui44. *PLoS Negl Trop Dis*. (2014) 8:e3103. doi: 10.1371/journal.pntd.0003103
47. Moreno LZ, Miraglia F, Kremer FS, Eslabao MR, Dellagostin AO, Lilembaum W, et al. Comparative genomics of pathogenic *Leptospira interrogans* serovar Canicola isolated from swine and human in Brazil. *Mem Inst O Cruz*. (2018) 113:126–9. doi: 10.1590/0074-02760170119
48. Costa F, Wunder EA. deOliveira D, Bisht V, Rodrigues G, Reis MG, et al. Patterns in *Leptospira* shedding in Norway rats (*Rattus norvegicus*) from Brazilian slum communities at high risk of disease transmission. *PLoS Negl Trop Dis*. (2015) 9:1–14. doi: 10.1371/journal.pntd.0003819
49. Guernier V, Lagadec E, Cordonin C, Minter GL, Gomard Y, Pagès F, et al. Human leptospirosis on Reunion Island, Indian Ocean: are rodents the (only) ones to blame? *PLoS Negl Trop Dis*. (2016) 10:e0004733. doi: 10.1371/journal.pntd.0004733
50. Biscornet L, Dellagi K. Pagès F, Bibi J, de Comarmond J, Mélade J, et al. Human leptospirosis in Seychelles: a prospective study confirms the heavy burden of the disease but suggests that rats are not the main reservoir. *PLoS Negl Trop Dis*. (2017) 11:e0005831. doi: 10.1371/journal.pntd.0005831
51. Flores BJ, Pérez-Sánchez T, Fuertes H, Scheleby-Elías J, Músquiz JL, Jíron W, et al. A cross-sectional epidemiological study of domestic animals related to human leptospirosis cases in Nicaragua. *Acta Trop*. (2017) 170:79–84. doi: 10.1016/j.actatropica.2017.02.031
52. Jorge S, Schuch RA, Oliveira NR, da Cunha CEP, Gomes CK, Oliveira TL, et al. Human and animal leptospirosis in Southern Brazil: a 5-year retrospective study. *Trav Med Infect Dis*. (2017) 18:46–52. doi: 10.1016/j.tmaid.2017.07.010
53. Pratt N, Conan A, Rajeev S. *Leptospira* seroprevalence in domestic dogs and cats on the Caribbean Island of Saint Kitts. *Vet Med Intern*. (2017) 2017:5904757. doi: 10.1155/2017/5904757
54. Rojas P, Monahan AM, Schuller S, Miller IS, Markey BK, Nally JE. Detection and quantification of leptospires in urine of dogs: a maintenance host for the zoonotic disease leptospirosis. *Eur J Clin Microbiol Infect Dis*. (2010) 29:1305–9. doi: 10.1007/s10096-010-0991-2
55. Llewellyn JR, Krupka-Dyachenko I, Rettinger AL, Dyachenko V, Stamm I, Kopp PA, et al. Urinary shedding of leptospires and presence of *Leptospira* antibodies in healthy dogs from Upper Bavaria. *Berl Munch Tierarztl Wochenschr*. (2016) 129:251–257.
56. Miller MD, Annis KM, LunnKF. Variability in results of the microscopic agglutination test in dogs with clinical leptospirosis and dogs vaccinated against leptospirosis. *J Vet Intern Med*. (2011) 25:426–32. doi: 10.1111/j.1939-1676.2011.0704.x
57. Haake DA, Levett PN. Leptospirosis in humans. *Curr Top Microbiol Immunol*. (2015) 387:65–97. doi: 10.1007/978-3-662-45059-8_5
58. Cumberland P, Everard CO, Levett PN. Assessment of the efficacy of an IgM-elisa and microscopic agglutination test (MAT) in the diagnosis of acute leptospirosis. *Am J Trop Med Hyg*. (1999) 61:731–4. doi: 10.4269/ajtmh.1999.61.731
59. Casanovas-Massana A, Costa F, Riediger IN, Cunha M, de Oliveira D, Mota DC, et al. Spatial and temporal dynamics of pathogenic *Leptospira* in surface waters from the urban slum environment. *Water Res*. (2017) 130:176–84. doi: 10.1016/j.watres.2017.11.068
60. Araújo WN, Finkmoore B, Ribeiro GS, Reis RB, Felzemburgh RDM, Hagn JE, et al. Knowledge, attitudes, and practices related to leptospirosis among urban slum residents in Brazil. *Am J Trop Med Hyg*. (2013) 88:359–63. doi: 10.4269/ajtmh.2012.12-0245
61. Trevejo RT, Rigau-Pérez JG, Ashford DA, McClure EM, Jarquín-González C, Amador JJ, et al. Epidemic leptospirosis associated with pulmonary hemorrhage—Nicaragua, 1995. *J Infect Dis*. (1998) 178:1457–63. doi: 10.1086/314424
62. Azócar-Aedo L, Monti G. Meta-analyses of factors associated with leptospirosis in domestic dogs. *Zoon Publ Health*. (2016) 63:328–36. doi: 10.1111/zph.12236
63. Hashimoto VY, Gonçalves DD, da Silva FG, de Oliveira RC, Alves LA, Reichmann P, et al. Occurrence of antibodies against *Leptospira* spp. in horses of the urban area of Londrina, Paraná, Brazil. *Rev Inst Med Trop S Paulo*. (2007) 49:327–30. doi: 10.1590/S0036-46652007000500010
64. Finger MA, Barros Filho IR, Leutenegger C, Estrada M, Ullmann LS, Langoni H, et al. Serological and molecular survey of *Leptospira* spp. among cart horses from an endemic area of human leptospirosis in Curitiba, Southern Brazil. *Rev Inst Med Trop S Paulo*. (2014) 56:473–6. doi: 10.1590/S0036-46652014000600003
65. Hamond C, Martins G. Bremont S, Medeiros MA, Bourhy P, Lilembaum W. Molecular characterization and serology of *Leptospira kirschneri* (Serogroup Grippotyphosa) isolated from urine of a mare post-abortion in Brazil. *Zoon Publ Health*. (2016) 63:191–5. doi: 10.1111/zph.12224
66. Kurilung A, Chanchaithong P, Lugsomya K, Niyomtham W, Wuthiekanun V, Prapasarakul N. Molecular detection and isolation of pathogenic *Leptospira* from asymptomatic humans, domestic animals and water sources in Nan province, a rural area of Thailand. *Res Vet Sci*. (2017) 115:146–54. doi: 10.1016/j.rvsc.2017.03.017
67. Pereira MM, Schneider MC, Munoz-Zanzi C, Costa F, Benschop J, Hartskeerl R, et al. A road map for leptospirosis research and health policies based on country needs in Latin America. *Rev Panam Salud Publica*. (2017) 41:e131. doi: 10.26633/RPSP.2017.131

Conflict of Interest: CM was employed by the company AAC&T Research Consulting LTDA.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Public Health

PERSPECTIVE
published: 25 February 2021
doi: 10.3389/fpubh.2021.637901

Biodiversity and Human Health Interlinkages in Higher Education Offerings: A First Global Overview

*Mark Cianfagna[1,2], Isabelle Bolon[1], Sara Babo Martins[1], Elizabeth Mumford[3], Cristina Romanelli[4], Sharon L. Deem[5], Christina Pettan-Brewer[6], Daniela Figueroa[7], Juan Carlos Carrascal Velásquez[8], Cheryl Stroud[9], George Lueddeke[10,11], Beat Stoll[1] and Rafael Ruiz de Castañeda[1]**

[1] Department of Community Health and Medicine, Faculty of Medicine, Institute of Global Health, University of Geneva, Geneva, Switzerland, [2] Global Studies Insitute, University of Geneva, Geneva, Switzerland, [3] World Health Organization, Geneva, Switzerland, [4] Department of Environment, Climate Change and Health, World Health Organization, Geneva, Switzerland, [5] Institute for Conservation Medicine, St. Louis Zoo, St Louis, MO, United States, [6] Department of Comparative Medicine, School of Medicine, University of Washington, Seattle, WA, United States, [7] Faculty of Liberal Arts, Adolfo Ibáñez University, Santiago, Chile, [8] One Health Colombia, Veterinary Medicine and Zootechnics Faculty, University of Córdoba, Cordoba, Colombia, [9] One Health Commission, Apex, NC, United States, [10] One Health for One Planet Education Initiative, Southampton, United Kingdom, [11] Centre for the Study of Resilience, Faculty of Education, University of Pretoria, Pretoria, South Africa

OPEN ACCESS

Edited by:
Hans Keune,
Belgian Biodiversity Platform, Belgium

Reviewed by:
Henrik Lerner,
Ersta Sköndal University College, Sweden
Laura H. Kahn,
Princeton University, United States

Correspondence:
Rafael Ruiz de Castañeda
rafael.ruizdecastaneda@unige.ch

Specialty section:
This article was submitted to Planetary Health, a section of the journal Frontiers in Public Health

Received: *04 December 2020*
Accepted: *01 February 2021*
Published: *25 February 2021*

Citation:
Cianfagna M, Bolon I, Babo Martins S, Mumford E, Romanelli C, Deem SL, Pettan-Brewer C, Figueroa D, Velásquez JCC, Stroud C, Lueddeke G, Stoll B and Ruiz de Castañeda R (2021) Biodiversity and Human Health Interlinkages in Higher Education Offerings: A First Global Overview. Front. Public Health 9:637901. doi: 10.3389/fpubh.2021.637901

Introduction: Biodiversity is inextricably linked to human health. As an important area of research of the Convention on Biological Diversity and a key avenue for the dissemination of biodiversity and health knowledge, we investigated how well-embedded biodiversity and health interlinkages are in institutional higher education offerings.

Methods: Using One Health education programs as a starting point, we collected a global list of institutions potentially carrying out education in the links between biodiversity and health through previously published research, academic partners of global conglomerates, and our own networks. We then analyzed the offerings from these institutions to determine the degree of integration of biodiversity and health interlinkages.

Results: We found 105 educational offerings in biodiversity and health interlinkages from 89 institutions in 30 countries. These were primarily found in faculties of public health, veterinary sciences, and medicine, with varying degrees of coverage of the interlinkages.

Conclusion: Education incorporating the links between biodiversity and health exists globally, but should be more widely integrated, particularly through inter-faculty and inter-institutional collaboration.

Keywords: one health, biodiversity, education, global health, planetary health, conservation, capacity-building, climate change

INTRODUCTION

The Earth has lost 68% of its ecosystems and associated biodiversity in the last 50 years due to anthropogenic activity (1, 2). The consequences of this unprecedented global ecological and environmental disruption are now more daunting than ever before, especially if we consider the increasing number of pathogen spillover events from wildlife and domestic animals to humans (3, 4). However, outside of the One Health community, recognition of the importance of ecosystems and biodiversity for human health is often lacking. Along with climate change response, the international community needs to focus on biodiversity conservation by emphasizing holistic approaches to health such as One Health and Planetary Health (5). In 2015, the Secretariat of the Convention on Biological Diversity (CBD) and the World Health Organization (WHO), with contributions from over 100 international experts, published "*Connecting Global Priorities: Biodiversity and Human Health - A state of knowledge review*" (6). The report provides a comprehensive review of the numerous ways in which biodiversity underpins health and the health risks associated with ecosystem disruption and biodiversity loss.

The Strategic Plan for Biodiversity and its 20 Aichi Biodiversity Targets adopted by the Conference of the Parties to the CBD in 2010, provided a 10-year overarching framework for action on biodiversity to 2020 (7). Aichi Targets 1 and 19 addressed the knowledge deficiency in biodiversity and attempted to increase the awareness and appreciation in the general public as well as increase knowledge, the science base and technologies related to biodiversity. Governments have largely failed to meet the overwhelming majority of the Targets to 2020, however Targets 1 & 19 are among the few that have seen progress (8, 9). The achievements of these targets can be furthered by interdisciplinary educational institutions' integration of biodiversity and its interlinkages to human health.

In academic curricula, biodiversity is typically covered in biology and ecology courses but increasingly also in the fields of economics, geology and anthropology (10, 11). In the field of veterinary medicine, public health and more recently in areas such as tropical medicine and a few institutions of human medicine, biodiversity interlinkages are gradually being introduced as part of One Health and global health curricula, particularly in the context of zoonotic emerging infectious diseases (12, 13).

Educational programs and courses teaching One Health can now be found in faculties of veterinary medicine, public health, human medicine and applied sciences at all levels of instruction. In 2016, there were 83 academic One Health programs and courses listed in North America alone (14). Further lists of these offerings were developed in Western Europe, China, South Asia, Sub-Saharan Africa and Australia/New Zealand; but did not include South America where One Health is gaining considerable importance (14–19).

With the need for more scientific, political and societal attention to the interlinkages between biodiversity and health in order to prevent future pandemics and reduce environmental disruption (4), we set out to explore if, where, and to what extent, biodiversity and health interlinkages are covered in higher education courses, programs, modules and certificates ('offerings', hereafter) worldwide and in high biodiversity areas (biodiversity hotspots), in particular (20).

METHODOLOGY

As biodiversity and its links to health is part of a wide One Health approach, we first collected lists of offerings from institutions teaching One Health as identified in previous publications (14–19, 21).

Second, Partner institutions of internationally recognized platforms including One Health Commission (www.onehealthcommission.org), Consortium of Universities for Global Health (www.cugh.org), EcoHealth Alliance (www.ecohealthalliance.org) and Planetary Health Alliance (www.planetaryhealthalliance.org), were screened for offerings with biodiversity and health interlinkages.

Thirdly, additional programs and institutions were added through a web search in English using Google between May and July 2020 using the following keywords: "One Health education," "One Health program," "One Health course," "One Health training," "planetary health education," "planetary health program," "planetary health course," "planetary health training," "biodiversity and health" "biodiversity and health training" "biodiversity and health education" "biodiversity and health course," "biodiversity and health program." Major massive open online course (MOOC) platforms, namely Coursera, Udemy, EdX, FutureLearn and Udacity, were also searched using the following keywords: "One Health," "planetary health," "biodiversity and health."

Lastly, to identify further institutions and their offerings, we performed consultations involving experts from One Health Commission, EcoHealth Alliance, and One Health Latin America and the Caribbean. Additional One Health experts in the authors' networks and the network of these were consulted. Overall, we reached out to 23 experts and spoke to 14. Through these consultations, institutions and programs in French, Spanish and Portuguese were added. For each institution listed, program descriptions, course descriptions and course syllabi (where available) were analyzed for offerings which included biodiversity and health interlinkages.

Six key biodiversity and health interlinkages are highlighted in the CBD/WHO State of Knowledge Review: ecosystem services (including pollination, food security and availability, nutrition, water quality, and air quality); climate change adaptation and disaster risk reduction (DRR); the human microbiome; traditional medicine/pharmaceuticals; spiritual, cultural and physical well-being; and emerging infectious diseases (EIDs).

Any offering which included explicit mention of one or more of these interlinkages was included in our offerings dataset. Offerings had to be available yearly with the same or similar topics, therefore one-off seminars and workshops were not included. Institutions and their offerings were excluded from in-depth review if no formal mention of training or education in biodiversity and health interlinkages or One Health was listed. Offerings from institutions which had indirect or unclear offerings were included in the mapping to emphasize regional distribution and as areas for further incorporation and capacity-building. Indirect offerings describe offerings which cover topics related to biodiversity and health interlinkages, but where there is no explicit mention of their interlinkages (ex. food safety, zoonoses, infectious disease). Unclear offerings describe offerings in which inadequate information was available to confirm coverage of interlinkages, but based on the title of the offering, it is plausible that there is coverage (ex. Master of One Health at University of Alaska Fairbanks).

RESULTS

A total of 341 institutions worldwide were screened for inclusion, with 219 included for in-depth review. These institutions were

FIGURE 1 | Distribution of institutions teaching biodiversity and health interlinkages (blue icons, $n = 88$). Yellow icons represent those with indirect offerings ($n = 28$); red icons, unclear offerings ($n = 18$). Distribution is overlaid on biodiversity hotspots (22).

found through previous publications ($n = 96$), international platforms ($n = 213$), Google and MOOC platform searches ($n = 13$), and expert consultations ($n = 19$).

From the 219 institutions reviewed, 105 offerings from 89 institutions and 30 countries were included in the dataset (**Supplementary Table**). Our data showed an important regional imbalance toward North America and Europe, where 68% of the institutions teaching biodiversity and health interlinkages are found. Oceania and Asia represented another 20%, leaving 12% of the programs split between Africa and Latin America and the Caribbean (**Figure 1**). Among the institutions included in our findings, 30 (34%) of them are located within biodiversity hotspots and 62 (70%) are in countries with biodiversity hotspots, as defined by Myers et al. (20) (over half of these being in the United States of America) (See **Figure 1**).

Offerings were found primarily in public health, veterinary medicine and human medicine faculties (22, 19, and 15%, respectively). Other faculties ranged from anthropology to forestry to sustainable development. The offerings targeted the spectrum of higher education, from open-access online courses to undergraduate, graduate, post-graduate, doctorate, and post-doctoral offerings, to continuing education for professionals. Most common were graduate-level offerings (50%), followed by undergraduate offerings (20%). There were some offerings available to professionals, typically from the public health and veterinary field. Often these were formatted as online continuing education modules or intensive short courses.

The majority of offerings covered only one or two of the biodiversity and health interlinkages (82 of 105, or 78%), while just six of them covered four of these. Encouragingly, the offerings covering three to four interlinkages (22%) came from a wide variety of faculties including human and veterinary medicine, public health, environmental science and biology. The most common interlinkages covered were ecosystem services [79 of the 105 offerings (75%)] and climate change adaptation & DRR (51%). Biodiversity and EIDs (45%) was often offered alongside ecosystem services and/or climate change. Topics such as spiritual, cultural and physical well-being, the human microbiome and traditional medicines/pharmaceuticals, all recognized as relevant areas of intersection in the State of Knowledge review, were not well-represented across the institutions (24% combined) (**Figure 2**).

DISCUSSION

There is an apparent geographical bias in institutions teaching biodiversity and health interlinkages. The majority of institutions in our dataset are based in Western Europe and North America. There is also a bias toward certain biodiversity and health interlinkages, notably ecosystem services and climate change. Many of the offerings covered only a small number of the interlinkages searched for, but offerings were found in a wide variety of faculties.

Our data show that biodiversity and health interlinkages are taught most often in public health offerings. This is likely due to the longer history of recognition of the interdisciplinary nature of public health (23). Schools of public health tend to promote inclusion of students from a variety of

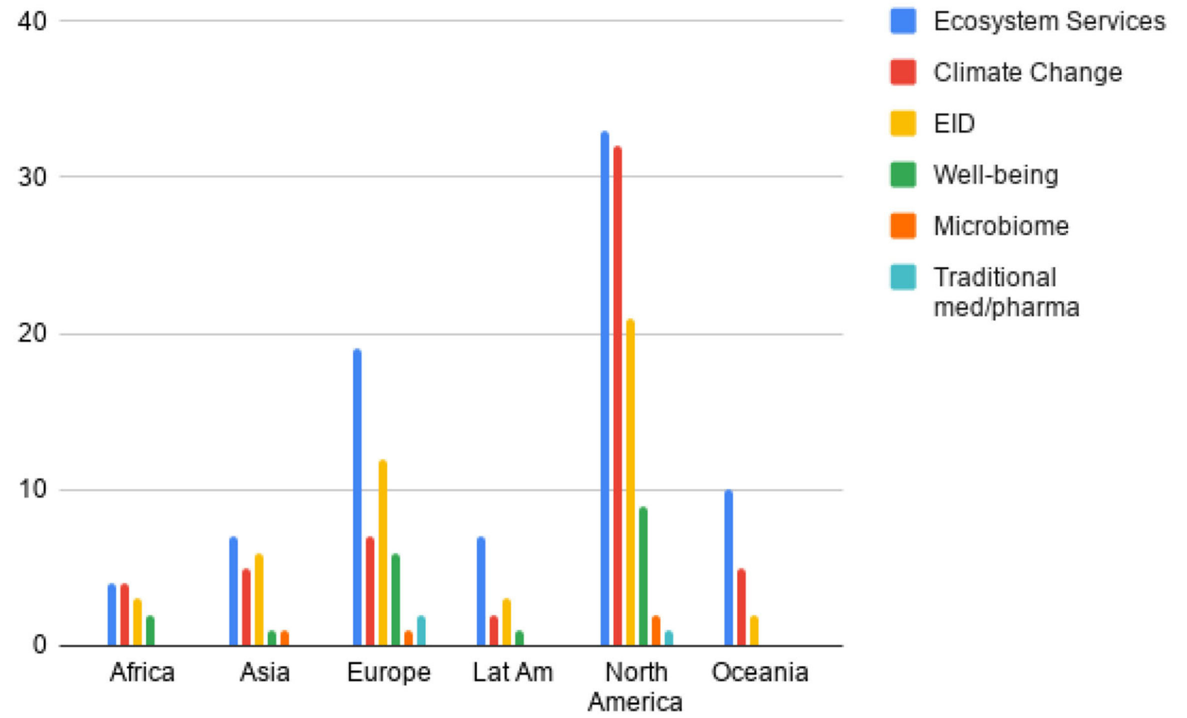

FIGURE 2 | Coverage of biodiversity and health interlinkages throughout offerings by region (LatAm, Latin America and the Caribbean; EID, Emerging Infectious Diseases).

disciplines including physicians, nurses, veterinarians, biologists, psychologists, economists, lawyers etc. Schools of public health offering teaching in biodiversity and health interlinkages (often embedded in One Health-focused courses and programs) have some of the most comprehensive programs we found, likely because public health has long recognized the necessity for interdisciplinary and cross-sectoral collaborations and the development of a diverse workforce with knowledge of current biodiversity and health challenges (24). In our results, all six of the biodiversity and health interlinkages were found in at least one offering from a school of public health. This breadth of coverage of biodiversity and health interlinkages, and the diversity of student's backgrounds and experience in public health programs, currently makes them particularly well-suited to fostering leadership in combined biodiversity and health education.

Veterinary and human medicine programs tend to be very clinically focused and there are associated challenges of finding the space within an already well-established curriculum to incorporate new topics and content (25). Suggestions to better incorporate these concepts into veterinary education include pre-clinical education (where applicable), common coursework with medical and science students and interdisciplinary faculty working across multiple domains (26–28). These ideas do not represent fundamental changes in veterinary education, but applied learning strategies that can be introduced without overhauling existing programs. Indeed, population biology is an overarching theme in veterinary medical education, and thus biodiversity could also be included. In human medicine, physicians are rarely trained to understand, or to inform the public, about the interlinkages between biodiversity and human health, or how to apply nature-based solutions or ecosystem services in their clinical practice (29). Medical school curricula are highly standardized and clinically focused. There is often little room for advancement in more general themes and systemic approaches to health outside of the clinical setting. Clinical, rather than population level, applications of biodiversity and health interlinkages may be a way to achieve integration into medical programs (30). These applications can include the contribution of biodiversity to dietary quality and nutritional assessment, green prescriptions and conservation psychology (31–33). These are all examples of interlinkages that can be included within specialized courses already integrated in human medical curricula. However, for most biodiversity and health interlinkages, population-level applications are of highest importance. Other research suggests looking to external bodies and elective courses for integration of these interlinkages (29, 34). While simpler, this would mean only a small proportion of physicians would be trained to acknowledge and apply biodiversity and health interlinkages into their practice.

The interest of integrating topics and approaches rather than separate disciplines in higher education course offerings is that there is no need to shoehorn another course into an already packed curriculum. Having learning outcomes such as values, knowledge and skills in an approach can help with integration in health professional education (35). These topics

TABLE 1 | Number of educational offerings per region separated according to target level of education and faculty offering the education opportunity.

	Target Level of Education*			Faculty			
	Undergraduate	Graduate	Professional Ed.	Public health	Veterinary	Medicine	Other
Africa	0	4	2	2	0	0	4
Asia	1	6	2	3	2	2	2
Europe	2	20	3	1	5	9	12
Lat Am	3	3	3	1	3	1	2
North America	15	29	4	16	7	7	17
Oceania	4	8	0	1	4	0	6

**some offerings open to multiple levels of education.*

can be included throughout educational programs as case studies, individual lectures and mandatory readings to support what is already being taught, allowing practitioners to have a more complete view of upstream drivers of health. Every medical program discusses infectious disease, so emphasis should be also placed on how ecosystem disruption and degradation can play a significant role in the emergence and re-emergence of infectious disease, particularly considering the growing number of zoonotic spillover events. This is of particular interest for medical faculties located in hotspots of disease emergence (36). Key areas for this include Latin America, West Africa and Southeast Asia, where almost every country has areas with high biodiversity and high risk of infectious disease emergence. Yet our dataset showed only a small number of offerings covering biodiversity and health interlinkages in Latin America, with only two highlighting EIDs. Future medical practitioners should be made aware of the risks associated with EIDs and the need for cross-sectoral surveillance in collaboration with veterinarians and other professionals.

Capacity-building projects to train professionals in One Health approaches can be a way to build regional and national resilience while preventing the major drivers of biodiversity loss and its effects on health (37). In our search, we found offerings not only for students but interdisciplinary high-level training for professionals which is key for region-specific, adaptable education (see **Table 1**). Local collaborations such as communities of practice are a way to encourage peer-to-peer education and research as well as capacity- building in education (38). Collaborations like these between faculties, universities, and development organizations allow for wider integration of biodiversity and health interlinkages and are key for distribution of knowledge (39). This is also an opportunity to address the regional institutional bias. Institutions with established teaching in the interlinkages of biodiversity and health should develop further partnerships with institutions in other areas of the world, particularly those in biodiversity hotspots, to build capacity and share knowledge (See **Figure 1**). There are examples of this working in the past (40) and One Health University networks in Southeast Asia and Africa, as well as One Health groups in Latin America, are great examples of current collaborations working to establish a stronger One Health workforce.

Although more prevalent in human and animal sciences, our data shows that these topics can also be found in faculties of science, agriculture, forestry, environment, development, public affairs, arts and anthropology. This variety of faculties, with many being interdisciplinary, shows that teaching in biodiversity and health interlinkages is available to a wide range of learners with many different backgrounds. It also allows for inter-faculty collaboration and mobility of students across faculties for fortified learning experiences (30, 41, 42). This demands institutional capacity and the willingness to incorporate the necessary reform of funding for interdisciplinary research and educational offerings (40). It also requires shifting away from purely curative approaches to health, toward more comprehensive approaches also focused on prevention. It is through this collaboration and adaptability that 'sustainable curricula' can be developed (43, 44). Whether on a global scale with large institutional partnerships or a local scale with inter-faculty collaboration, education in biodiversity and health interlinkages can have a much wider reach.

There is also opportunity for broader incorporation of the interlinkages through the expansion of One Health research already existing in several institutions. Research like that by Togami et al. (45), which lays out step-by-step approaches to incorporating One Health concepts into academic programs, are very informative for institutions and can aid them in adjusting complicated curricula. As shown, multiple institutions around the world are integrating biodiversity and health interlinkages into their teachings in a variety of disciplines. However, more can be done to integrate these concepts into a wider variety of programs and to reach a wider audience. The understanding of human connection to the natural world has been brought to the forefront due to the COVID-19 pandemic. Studies have shown large increases in the use of green spaces and searches for the connection of the current crisis to nature (46–48). COVID-19 has provided us with a reinforcement of the need for more work to protect biodiversity for our own health and may create more opportunities for education as the world adapts to a new understanding of ecosystem function. Education, with particular emphasis on the unifying One Health concept, remains a key to global sustainability (44). As the world moves into another decade, one the UN has described as the UN Decade on Ecosystem Restoration (49), teaching in biodiversity and its links to global health and well-being should be expanded throughout higher education offerings.

LIMITATIONS

This being a first preliminary overview, with a simple, yet rigorous methodology, we could not comprehensively cover all offerings worldwide. Some may have been missed in the initial searches due to language or availability of information on the web or in published literature. For instance, ecohealth was not used as a search keyword in the methodology due to initial searches turning up few results and opportunities in ecohealth education being captured through partner institutions of the EcoHealth Alliance. Our consultations were also limited to Latin America, partly due to the research focus of the special issue of this journal. Further consultation with colleagues in Europe, Africa and Asia would surely reveal other offerings. We also recognize the importance of workshops, conferences and seminars as important capacity-building activities which can lead to deeper institutional integration of the interlinkages, especially for in-service professionals. This is beginning to show in Latin America as One Health activities grow through institutions with strong One Health leadership. Next steps will include more localized surveys of faculties in order to discover more educational offerings. In fact, we have already started this in Brazil and other Latin American countries. Further discussions and a chance to distribute surveys such as Omrani et al. (50) did for climate change with medical students will allow for a more complete picture of higher education offerings in the interlinkages of biodiversity and health.

CONCLUSION

This preliminary overview has shown that biodiversity and health interlinkages are increasingly being integrated into a wide variety of higher education institutions and their educational offerings worldwide. Further integration with wider coverage of biodiversity and health interlinkages is especially needed in institutions within biodiversity hotspots as these are the places most likely to experience the direct health effects of biodiversity loss. This can be accomplished through inter-faculty and inter-institutional collaboration and restructuring of funding for interdisciplinary research. With growing attention to the interlinkages between biodiversity and human health through recent pandemics and the decade on ecosystem restoration, we hope to see greater integration of these vital links into higher education.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

MC main writing of article, collected and analyzed data, hosted weekly meetings, identified, and completed consultations. RRdC head supervisor of project, coordinating author, concept development, contributed to weekly meetings, provided connections to network, and reviewed text. BS reviewed text and integral supporter of authors in Geneva. GL connected authors with network and reviewed text. JV added data to dataset in Spanish and helped develop survey for Latin America. DF added data to dataset in Spanish and reviewed text. CS connected first author with network and helped to fill in areas of data deficiency in Latin America. CP-B added data to dataset in Portuguese, connected authors to network, and developed survey for LatAm. SD added data to dataset and reviewed and revised manuscript text providing further references and perspective. CR consult on project, reviewed and revised text, adding perspective, and further references. EM reviewed and revised multiple drafts of text, making significant changes. SM concept development, review and revision of all drafts of text, and consultation throughout process. IB regular advisor on project, concept development, added data to dataset in French, and contributed to weekly meetings. All authors contributed to the article and approved the submitted version.

ACKNOWLEDGMENTS

The authors would like to acknowledge Drs. Daniel Brandespim, Juliana Galhardo, and Sergio Scott of One Health Brasil for the continuing collaborative research and survey data in LatAm which will be published in the near future. We would also like to acknowledge Catherine Machalaba of EcoHealth Alliance for her contributions in the early discussions and development of this project. Finally, we thank Prof Antoine Flahault, Prof Francois Chappuis and Dr. Jean Simos for their leadership and support of One Health research and education at the University of Geneva.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2021.637901/full#supplementary-material

REFERENCES

1. Almond REA, Grooten M, Petersen T. (Eds). *Living Planet Report 2020 - Bending the Curve of Biodiversity Loss*. Gland: WWF (2020).
2. Brondizio ES, Settele J, Díaz S, Ngo HT (Eds). *IPBES: Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. Bonn: IPBES secretariat (2019).
3. Gibb R, Redding D, Chin K, Donnelly C, Blackburn T, Newbold T, et al. Zoonotic host diversity increases in human-dominated ecosystems. *Nature*. (2020) 584:398–402. doi: 10.1038/s41586-020-2562-8
4. Daszak P, das Neves C, Amuasi J, Hayman D, Kuiken T, Roche B, et al. *IPBES Workshop Report on Biodiversity and Pandemics of the*

Intergovernmental Platform on Biodiversity and Ecosystem Services. Bonn: IPBES secretariat (2020).

5. Horton R. Planetary health's next frontier—biodiversity. *Lancet*. (2017) 390:2132. doi: 10.1016/S0140-6736(17)32843-X
6. World Health Organization and Secretariat of the Convention on Biological Diversity. *Connecting Global Priorities: Biodiversity and Human Health a State of the Knowledge Review*. Geneva: WHO Press (2020).
7. Secretartiat of the Convention on Biological Diversity. *Aichi Biodiversity Targets*. (2020). Available online at: https://www.cbd.int/sp/targets/ (accessed July 12, 2020).
8. Secretariat of the Convention on Biological Diversity. *Global Biodiversity Outlook 5*. Montreal: CBD (2020).
9. European Environment Agency. *Public Awareness of Biodiversity in Europe*. (2019). Available online at: https://www.eea.europa.eu/data-and-maps/indicators/public-awareness-2/assessment (accessed July 5, 2020).
10. Kumar P (ed.). *An Output of TEEB: The Economics of Ecosystems and Biodiversity*. London: Earthscan (2010).
11. Lewis S, Maslin M. Defining the anthropocene. *Nature*. (2015) 519:171–80. doi: 10.1038/nature14258
12. Walpole S, Barna S, Richardson J, Rother H. Sustainable healthcare education: integrating planetary health into clinical education. *Lancet Planetary Health*. (2019) 3:e6–7. doi: 10.1016/S2542-5196(18)30246-8
13. Romanelli C, Cooper H, de Souza Dias B. The integration of biodiversity into one health. *Sci Tech Rev Office Int Epizooties*. (2014) 2:487–96. doi: 10.20506/rst.33.2.2291
14. Stroud C, Kaplan B, Logan J, Gray G. One health training, research, and outreach in North America. *Infect Ecol Epidemiol*. (2016) 6:33680. doi: 10.3402/iee.v6.33680
15. Reid S, McKenzie J, Woldeyohannes S. One health research and training in Australia and New Zealand. *Infect Ecol Epidemiol*. (2016) 6:33799. doi: 10.3402/iee.v6.33799
16. McKenzie J, Dahal R, Kakkar M, Debnath N, Rahman M, Dorjee S, et al. One health research and training and government support for one health in South Asia. *Infect Ecol Epidemiol*. (2016) 6:33842. doi: 10.3402/iee.v6.33842
17. Sikkema R, Koopmans M. One health training and research activities in Western Europe. *Infect Ecol Epidemiol*. (2016) 6:33703. doi: 10.3402/iee.v6.33703
18. Rwego I, Babalobi O, Musotsi P, Nzietchueng S, Tiambo C, Kabasa J, et al. One Health capacity building in sub-Saharan Africa. *Infect Ecol Epidemiol*. (2016) 6:34032. doi: 10.3402/iee.v6.34032
19. Wu J, Liu L, Wang G, Lu J. One health in China. *Infect Ecol Epidemiol*. (2016) 6:33843. doi: 10.3402/iee.v6.33843
20. Myers N, Mittermeier R, Mittermeier C, da Fonseca G, Kent J. Biodiversity hotspots for conservation priorities. *Nature*. (2000) 403:853–8. doi: 10.1038/35002501
21. Deem SL, Lane-deGraaf KE, Rayhel EA. *Introduction to One Health: An Interdisciplinary Approach to Planetary Health*. Hoboken, NJ: John Wiley & Sons, Inc. (2019).
22. Critical Ecosystem Partnership Fund. *Data From: Biodiversity Hotspots. ArcGIS*. (2016). Available online at: maps.arcgis.com/home/item.html?id=ba55aa1bff5447e7b72559b8dc1a0e83 (accessed July 20, 2020).
23. Dórea F, Dupuy C, Vial F, Reynolds T, Akkina J. Toward one health: are public health stakeholders aware of the field of animal health? *Infect Ecol Epidemiol*. (2014) 4:24267. doi: 10.3402/iee.v4.24267
24. Kahn L. The need for one health degree programs. *Infect Ecol Epidemiol*. (2011) 1:7919. doi: 10.3402/iee.v1i0.7919
25. Nielsen N, Waltner-Toews D, Nishi J, Hunter D. Whither ecosystem health and ecological medicine in veterinary medicine and education. *Canad Vet J*. (2012) 53:747–53. Available online at: https://www.ncbi.nlm.nih.gov/pubmed/23277641
26. McConnell I. One health in the context of medical and veterinary education. *Sci Tech Rev Office Int Epizooties*. (2014) 33:651–7 doi: 10.20506/rst.33.2.2304
27. Samad A. Current status and challenges for globalization of veterinary medical education for the one health programme. *Sci Techn Rev*. (2017) 6:741–65. doi: 10.20506/rst.36.3.2711
28. Chaddock M. Academic veterinary medicine and one health education: it is more than clinical applications. *J Vet Med Educ*. (2012) 39:241–6. doi: 10.3138/jvme.0612-062
29. Gomez A, Balsari S, Nusbaum, J, Heerboth A, Lemery J. Environment, biodiversity and the education of the physician of the future. *Acad Med*. (2013) 88:168–72. doi: 10.1097/ACM.0b013e31827bfbeb
30. Rabinowitz P, Natterson-Horowitz B, Khan L, Kock R, Pappaioanou M. Incorporating one health into medical education. *BMC Med Educ*. (2017)17:45. doi: 10.1186/s12909-017-0883
31. Lachat C, Raneri J, Smith K, Kolsteren P, Van Damme P, Verzelen K, et al. Dietary species richness as a measure of food biodiversity and nutritional quality of diets. *Proc Natl Acad Sci USA*. (2018) 115:127–32. doi: 10.1073/pnas.1709194115
32. Hamlin M, Yule E, Elliot C, Stoner L, Kathiravel Y. Long-term effectiveness of the New Zealand green prescription primary health care exercise initiative. *Public Health*. (2014) 140:102–8. doi: 10.1016/j.puhe.2016.07.014
33. Clayton S (ed.). *The Oxford Handbook of Environmental and Conservation Psychology*. Oxford: Oxford University Press (2012).
34. Frankson R, Hueston W, Christian K, Olson D, Lee M, Valeri L, et al. One health core competency domains. *Front Public Health*. (2016) 4:192. doi: 10.3389/fpubh.2016.00192
35. Barna S, Maric F, Simons J, Kumar S, Blankestijn P. Education for the anthropocene: planetary health, sustainable health care, and the health workforce. *Med Teacher*. (2020) 42:1091–6. doi: 10.1080/0142159X.2020.1798914
36. Allen T, Murray KA, Zambrana-Torrelio C, Morse SS, Rondinini C, Di Marco M, et al. Global hotspots and correlates of emerging zoonotic diseases. *Nat Commun*. (2017) 8:1124. doi: 10.1038/s41467-017-00923-8
37. UC Davis. *Predict Project*. (2020). Available online at: https://ohi.vetmed.ucdavis.edu/programs-projects/predict-project (accessed October 28, 2020).
38. Cole D, Parkes M, Saint-Charles J, Gislason M, McKellar K, Webb J. Evolution of capacity strengthening: insights from the Canadian community of practice in ecosystem approaches to health. *Transform Dialog.* (2018) 11:2.
39. Bolon I, Mason J, O'Keeffe P, Haeberli P, Abdi Adan H, Makamba Karenzi J, et al. One health education in Kakuma refugee camp (Kenya): from a MOOC to projects on real world challenges. One *Health*. (2020) 10:100158. doi: 10.1016/j.onehlt.2020.100158
40. One Health Network South Asia. Available online at: http://www.onehealthnetwork.asia/ (accessed November 3, 2020).
41. Allen-Scott L, Buntain B, Hatfield J, Meisser A, Thomas CJ. Academic Institutions and One Health: Building capacity for transdisciplinary research approaches to address complex health issues at the human animal interface. *Acad Med*. (2015) 90:866–71. doi: 10.1097/ACM.0000000000000639
42. Barret M, Bouley T, Stoertz A, Stoertz R. Integrating a one health approach in education to address global health and sustainability challenges. *Front Ecol Environ*. (2011) 9:239–45. doi: 10.1890/090159
43. Walpole S, Vyas A, Maxwell J, Canny B, Woollard R, Wellbery C, et al. Building an environmentally accountable medical curriculum through international collaboration. *Med Teacher*. (2017) 39:1040–50. doi: 10.1080/0142159x.2017.1342031
44. Lueddeke GR. *Survival: One Health, One Planet, One Future*. New York, NY: Routledge (2019).
45. Togami E, Gardy J, Hansen G, Poste G, Rizzo D, Wilson M, et al. *Core Competencies in One Health Education: What Are We Missing*. Washington, DC: National Academy of Medicine (2014).
46. Venter ZS, Barton DN, Gundersen V, Figari H, Nowell M. Urban nature in a time of crisis: recreational use of green space increases during the COVID-19 outbreak in Oslo, Norway. *Environ Res Lett*. (2020) 15:104075. doi: 10.1088/1748-9326/abb396
47. Samuelsson K, Barthel S, Colding J, Macassa G, Giusti M. *Urban Nature As a Source of Resilience During Social Distancing Amidst the Coronavirus Pandemic*. (2020). Available online at: https://doi.org/10.31219/osf.io/3wx5a (accessed April 17, 2020).
48. Rousseau S, Deschacht N. Public awareness of nature and the environment during the COVID-19 crisis. *Environ Res Econ*. (2020) 76:1149–59. doi: 10.1007/s10640-020-00445-w
49. United Nations. *Decade on Restoration*. (2020). Available online at: https://www.decadeonrestoration.org/ (accessed November 20, 2020).

50. Omrani OE, Dafallah A, Castillo BP, Amaro B, Taneja S, Amzil, M et al. Envisioning planetary health in every medical curriculum: an international medical student organization's perspective. *Med Teacher*. (2020) 42:1107–11. doi: 10.1080/0142159X.2020.1796949

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Public Health

MINI REVIEW
published: 22 April 2021
doi: 10.3389/fpubh.2021.624975

One Decade of Environmental Disasters in Brazil: The Action of Veterinary Rescue Teams

Carla Sássi[1], *Gabriel Domingos Carvalho*[2*], *Leonardo Maggio de Castro*[3], *Cláudio Zago Junior*[4], *Vânia de Fátima Plaza Nunes*[5], *Arthur Augusto Tavares do Nascimento*[6], *Ana Liz Ferreira Bastos*[7,8], *Luciana Guimarães Santana*[9] and *Ilka do Nascimento Gonçalves*[10]

[1] G.R.A.D. Grupo de Resgate de Animais em Desastres, Cuiabá, Brazil, [2] Federal Institute of Education, Science and Technology of Espírito Santo, Ifes Campus Piúma, Piúma, Brazil, [3] Large Animal Veterinary Hospital, University of Sorocaba, Sorocaba, Brazil, [4] Fire Brigade School, Military Police of São Paulo State, São Paulo, Brazil, [5] National Animal Protection and Defense Forum, Jundiaí, Brazil, [6] G.R.A.D. Grupo de Resgate de Animais em Desastres, Cuiabá, Brazil, [7] Regional Council of Veterinary Medicine of Minas Gerais—CRMV/MG, Belo Horizonte, Brazil, [8] Animal Welfare Commission of CRMV/MG, Belo Horizonte, Brazil, [9] Independent Researcher, Veterinary of Wild Animals, São Paulo, Brazil, [10] Independent Researcher, Private Veterinary Clinic, Bahia, Brazil

OPEN ACCESS

Edited by:
Christina Pettan-Brewer, University of Washington, United States

Reviewed by:
Nicole De Paula, Institute for Advanced Sustainability Studies (IASS), Germany
Lei Xu, Tsinghua University, China

***Correspondence:**
Gabriel Domingos Carvalho
gabriel.carvalho@ifes.edu.br

Specialty section:
This article was submitted to Planetary Health, a section of the journal Frontiers in Public Health

Received: *02 November 2020*
Accepted: *16 February 2021*
Published: *22 April 2021*

Citation:
Sássi C, Carvalho GD, de Castro LM, Junior CZ, Nunes VdFP, do Nascimento AAT, Bastos ALF, Santana LG and Gonçalves IdN (2021) One Decade of Environmental Disasters in Brazil: The Action of Veterinary Rescue Teams. Front. Public Health 9:624975. doi: 10.3389/fpubh.2021.624975

Based on the interdisciplinary concept of One Health, EcoHealth, and Planetary Health, this paper focuses on participatory knowledge-to-action approaches by relating one decade of environmental disasters in Brazil with the action of veterinary rescue teams, aiming to give support to future disaster preparedness. This paper will present the historic actions of teams rescuing animal that are victims of environmental disasters, in addition to addressing the need for contingency plans and response management in these types of events. The main events in Brazilian states where veterinary rescue teams participated were, chronologically, as follows: 2011 flood and landslide (Rio de Janeiro); 2012 flood (Acre, Minas Gerais, and Pará); 2015 dam break (Minas Gerais); 2017 flood (Minas Gerais) and forest fire (Minas Gerais and Goiás); 2019 dam break and evacuation (Minas Gerais) and flood (Bahia); 2020 flood (Espírito Santo and Minas Gerais) and forest fires (Mato Grosso and Mato Grosso do Sul). The Brazilian disasters that had a large global repercussion were the ruptures of the ore dams in Marina (2015) and Brumadinho (2019), both in the State of Minas Gerais. The role of veterinarians in these events was recognized by the Federal Council of Veterinary Medicine (CFMV) after their performance in Mariana, Minas Gerais (2015), and in 2020, the CFMV approved the National Mass Disaster Contingency Plan Involving Animals. The work of veterinarians in interaction with other professionals in environmental disasters proved to be effective and necessary for the rescue of animals and for planning and giving support to disaster preparedness in the future.

Keywords: Brazilian pantanal, Brumadinho, ecohealth, Mariana, one health, planetary health

INTRODUCTION

The term "disaster" has different concepts, but the concepts invariably refer to at least one of these factors: threat, vulnerability, risk, exposure, and responsiveness (1). Disasters, regardless of their technical classification, are undesirable and unpredictable events that generate great instabilities in an affected population, negatively impacting directly and indirectly environmental and socioeconomic conditions in a near or distant manner, depending on their magnitude (2).

In general, disasters devastate homes, establishments, and properties, destroying livelihoods and deteriorating essential services, damaging the individual and collective health of humans and animals, reflecting on injured individuals and a variable number of deaths, in addition to leading to damage to a greater and lesser extent and also to mental damage that may be transient or long-lasting (3).

Depending on the type of disaster, different demands are faced by the communities and teams responsible for providing support in the post-tragedy. For this, the professionals of these teams must have multidisciplinary skills from previous training, as well as adequate resources for proper support (4, 5). In some countries, such as the United States, disaster response teams are composed of firefighters, doctors, paramedics, engineers, and machinery operators (tractors and cranes), specialized in rescue, with the duty to locate, extract, and provide assistance (6, 7).

Adverse events, mainly of climatic origin such as droughts and forest fires, of hydrological origin such as runoffs and floods, and of meteorological origin such as heat waves and tropical cyclones, currently affect populations worldwide and particularly in Brazil. According to data from the United Nations International Strategy for Disaster Reduction (UNDRR), more than 200 million people are affected by disasters of different origins every year (1).

This paper will present a brief overview of the historic actions of volunteer veterinarians in rescuing animal victims of environmental disasters, in addition to addressing the need for contingency plans and response management in these types of events.

Environmental Disasters in Brazil

In Brazil, the occurrences of disasters, especially those of natural origin, coincide with the deterioration of living conditions in cities, with the occurrence of many damages and losses (1). It is estimated that these phenomena aggravate problem situations such as malnutrition, endemic infectious diseases, and accidents due to extreme events. Additional risks to public health must also be considered: excessive demand on health services, water supply problems, and increase in some diseases (8).

The main events with participation of veterinary rescue teams in Brazilian states were, chronologically, as follows: 2011 in Rio de Janeiro (flood and landslide); 2012 in Acre and Pará (flood) and Minas Gerais (flood); 2015 in Minas Gerais (dam break); 2017 in Minas Gerais (flood and forest fire) and Goiás (forest fires); 2019 in Minas Gerais (dam break and evacuation) and Bahia (flood); 2020 in Espírito Santo and Minas Gerais (flood) and in Mato Grosso and Mato Grosso do Sul (Pantanal forest fires) (9) (**Table 1**).

TABLE 1 | Main events with the participation of veterinary rescue teams in the Brazilian states on the last decade, chronologically.

Year	State	Cities/areas	Type of disaster
2011	Rio de Janeiro	Nova Friburgo and other municipalities	flood and landslide
2012	Acre	Rio Branco and Brasiléia	flood
	Pará	Santa Cruz do Arari	flood
	Minas Gerais	Tiradentes, Congonhas, Conselheiro Lafaiete, São João del Rei	flood
2015	Minas Gerais	Mariana and other municipalities in the course of river Doce	dam break
2017	Goiás	Alto Paraíso (*Chapada dos Veadeiros*)	forest fire
	Minas Gerais	Rio Casca	flood
		Ouro Branco	forest fire
2019	Minas Gerais	Brumadinho	dam break
		Barão de Cocais	preventive evacuation (risk of dam break)
	Bahia	Coronel João de Sá	dam break
2020	Espírito Santo	Iconha, Rio Novo do Sul, Alfredo Chaves, Cachoeiro de Itapemirim, Castelo, Vargem Alta, and other municipalities	flood
	Minas Gerais	various cities	flood
	Mato Grosso	various cities (*Pantanal*)	forest fire
	Mato Grosso do Sul	various cities (*Pantanal*)	forest fire

In January 2011, heavy rains triggered what would be considered the worst Brazilian natural disaster of recent times: the floods and landslides in the mountain region of Rio de Janeiro, an event that caused 905 deaths in seven cities and affected more than 300,000 people, which corresponded to 42% of the population of the affected municipalities, that is, 4.46% of the population of the State of Rio de Janeiro at the time. Total losses were estimated at US$3 billion; however, these omit relevant impacts in sectors such as education and health, which could not be considered due to unavailability of detailed information (1).

The national disasters, in Brazil, that had a large global repercussion were the ruptures of ore dams in Marina (2015) and Brumadinho (2019), both in the State of Minas Gerais, with is the state with highest number of disasters and consequentially rescue team actions (10). In the case of the Mariana disaster, even other states had been affected, for example, the State of Espírito Santo, where the mouth of the river Doce, sourced in Minas Gerais, is located. Some of these impacts were observed in estuarine fish, through tissue bioaccumulation and oxidative stress defenses observed in response to the contamination of the river Doce (11).

The most recent disaster in Brazil is the Pantanal fire in the States of Mato Grosso and Mato Grosso do Sul. In 2020, it is estimated that the fire destroyed 28% of the Brazilian Pantanal between January and October, as monitored by the Environmental Satellite Applications Laboratory at the Federal University of Rio de Janeiro (*Laboratório de Aplicações de Satélites Ambientais da Universidade Federal do Rio de Janeiro*

TABLE 2 | Main actions of rescue veterinary teams in cases of disasters.

Veterinary actions in animal rescues during disasters		
Before rescue	**During rescue action**	**After rescue**
1) survey of previous information of the affected areas (accesses, topography, activities developed in the place, type of residences, and others)	1) rescue of survivors	1) clinical follow-up of survivors
2) identification of the main animal species in the region	2) clinical and surgical care	2) transfer rescued animals to guardians or adopters
3) elaboration of the action plan	3) shelter installation	3) castration of the animals that will be sent for adoption
4) organization of first-aid work material (personal protective equipment, medicines, hospital supplies)	4) vaccination protocols and application of antiparasitic drugs	4) serological diagnosis for epidemiological investigation of endemic diseases in the affected region
5) water demand for survivors	5) providing water and food to survivors	5) Monitoring of zoonoses

[LASA/UFRJ]). Burnt areas increased by more than 100%, compared to the same period at the year previous to the disaster. Fire affected almost all conservation units and indigenous lands in the Pantanal region (12).

Disasters and Environmental, Human, and Animal Health

Disasters result in direct short-, medium-, and long-term effects as well as indirect effects on the health and well-being of populations. Among these effects, the following stand out: reduction of social welfare standards; deaths, traumas, and injuries; damage to the basic service structure; compromise of equipment and medicine stocks; proliferation of infectious and vector-borne diseases; and psychosocial damages (8). The most health-related problems involve the same complex, humans–animals and the environment, so government decision-making should be based on the pillars of the One Health concept, based on the knowledge produced and interconnected by different institutions, based on the problems found in society, acting from an intersectoral and multiprofessional perspective (13).

The measures adopted in veterinary medicine during disasters are based on the same pillars used for the human population; however, it is necessary to adjust them to the specific needs of different species (10). In **Table 2** are presented the main actions done by the rescue veterinary teams in case of disasters. Some rescue situations are high-risk scenarios and difficult for rescuers to access, as in the case of Brumadinho, which leads those responsible for rescuing the animals to adopt extreme measures but always backed by an ethical professional attitude (14).

The diagnosis of the situation of a specific affected area is of paramount importance to identify the main basic needs of the population in the region (15). Previous knowledge about the region and the database of the municipalities are essential to understand what activities are carried out there and the estimated number of properties, residents, and animals in the region. Sanitary and animal health data are important as a starting point for the formulation of specific epidemiological indicators (6, 10, 16).

Action of Veterinarians in Animal Rescues During Disasters

In 2011, with the catastrophe caused by heavy rains and landslides that had hit the mountainous region of the State of Rio de Janeiro, Brazil, in the city of Nova Friburgo, the first team of veterinary medical professionals, originating from the State of Minas Gerais, started to voluntarily train themselves to act in rescues of domestic animals in situations of environmental disasters (9).

Over the years, these groups realized the need for training so that their work has become increasingly technical and successful. The collective veterinary medicine is of great importance in this scenario and training, for having been a pioneer in addressing the theme of mass disasters and its impact on the lives of animals in Brazil. It is essential that professionals get deeper into collective veterinary medicine to act during mass disasters, since the area encompasses many aspects inherent to crisis scenarios, such as animal welfare, zoonoses, animal behavior, adoption, bioethics, human resource management, and even humanitarian education, balancing in these interfaces the elements that constitute unique health (9). In addition to these aspects, it is essential to train the teams and provide technical and psychological support (10).

Since then, the need to formalize and structure veterinary rescue groups arose. The Disaster Animal Rescue Group (*Grupo de Resgate de Animais em Desastres* [GRAD]) was officially created in 2019. Before the dam burst in Brumadinho, several professionals and volunteers that operate in disasters were included in the group. Important work fronts were developed and technologized, such as contingency plans, autopsies, vaccination and health of the team, and veterinary medicine from catastrophe animal shelters, in addition to the field rescue fronts. With the constant performance of veterinary professionals in catastrophes and with the insertion of a team in the Regional Council of Veterinary Medicine of Minas Gerais, a new line of professional activity originated, the veterinary medicine of disasters (17).

GRAD is a group constituting veterinarians and volunteers, which is acknowledged nationally by the National Animal Protection and Defense Forum (FNPDA), receiving support from civil society and from the Federal Council of Veterinary Medicine (CFMV), being nationally recognized for its experience in response to fauna affected by disasters (17). The main disasters where GRAD members had participated are listed in **Table 1**.

In view of this scenario of the last decade, there is a clear need to prepare veterinarians to work in this area, so that they can be recognized, respected, and inserted in an official way in disaster management operations, acting in parallel with the actions developed for the rescue of human lives. It is essential to recognize the role of animals in the family nucleus and human health and include them in disaster contingency plans, with a view to preventing and reducing the health risks arising from these disasters (18). Biosafety measures during disasters should be part of the operation and management plan to prevent anthropozoonoses, as they are essential for the well-being and health of humans, animals, and the environment, ensuring One Health (9).

National Mass Disaster Contingency Plan Involving Animals

In mass disasters, it is essential that there is articulation between several federal, state, and municipal institutions that can contribute to situations involving animals, such as environment, agriculture, public health, police, public ministry, civil defense, firefighter, education, and civil society organizations. It is essential that contacts and partnerships between institutions and support bodies begin even before the occurrence of a disaster, to harmonize contingency strategies and plans and to promptly implement them, correctly and at the right time (9). There is a need for information and surveillance systems integrated between areas such as public health, civil defense, and environmental defense to analyze the effects of disasters on the health of populations (19).

In Brazil, the National Civil Protection and Defense Policy (PNPDEC), established through Law 12608/2012, provides that civil defense and protection actions are organized by prevention, mitigation, preparation, response, and recovery actions. Thus, for each of them, there are specific responsibilities, while they are part of a systemic and continuous management. However, this policy does not detail the actions related to animals as among the main actions to assist victims of disasters; it mentions only the management of domestic animals and the burial of animals in appropriate places, according to zoonosis rules (1), not considering the whole concept of One Heath.

The creation of action plans for animal rescue in environmental disasters requires good strategic planning and investment of resources, participation of public authorities, qualified training of the professionals involved, and the awareness of the population about basic preventive actions (20). The groups and official bodies that deal with mass disasters in Brazil, in general, do not have the participation of professionals specialized in the care of animals. Thus, veterinary medical professionals have been assuming this role on a voluntary basis for some years (9).

In October 2020, the CFMV of Brazil approved the National Mass Disaster Contingency Plan Involving Animals to support the conduct of professionals working in the field (21). The document provides guidelines for the performance of professionals in scenarios of this nature, with guidelines on how to conduct rescue, veterinary assistance, maintenance, and disposal of domestic and wild animals. The plan is a milestone and has become the reference for professionals working in all states of the country (22).

The plan is the result of the CFMV's Mass Disaster Involving Animals Working Group, which was attended by members of GRAD, to support actions in the response and prevention of the next disasters, which generate impacts for society, with implications for public health, the economy, and the emotions of the affected population, especially of animals that are vulnerable, be they companionship, production, or wild animals. According to the CFMV, the construction of the plan was only possible by observing and documenting the difficulties faced in national disasters that have occurred since 2011, with the floods and landslides of Nova Friburgo, in Rio de Janeiro; the ruptures of dams in Mariana (2015) and Brumadinho (2019), in Minas Gerais; and the fires in the Pantanal (2020) (23).

The National Contingency Plan for Mass Disasters Involving Animals brings together the experience of professionals from various segments of activity, considering the particularities of the species and the potential disasters expected for Brazil. The plan considered aspects of approaching the scenario and making decisions involving the care and rescue of the various species; their habits, food, accommodation, transportation, and health; and all the spheres that need to be understood so that prevention, response, and/or recovery are successful, ensuring the rescue of animals and guaranteeing their well-being and quality of life, with clear and concise guidelines. It is believed that the plan will be an important marker of activities related to the theme in future situations, which cannot be predicted, but for which one must be prepared (9).

Technical preparation, hierarchy, and communication in the context of a disaster are essential for the safety of professionals, people, and animals, as well as for planning and decision making. However, to make effective and assertive conducts feasible in handling these situations, the accurate compilation of information and data by the situation diagnosis team is vital, helping to mobilize efforts and adequate resources for the operation (17). Previous planning deserves emphasis and gains great prominence for the positive execution of operations, which is sometimes more important and effective than frontline actions in the field. The alignment of disaster veterinary medicine professionals with official municipal, state, and federal agencies is essential for the success of rescue actions (24).

Technical rescue of animals in disaster scenarios involves planning and, at the same time, requires speed. To facilitate the conduct of professionals, the National Mass Disaster Contingency Plan Involving Animals highlights eight steps to be observed, aiming at the health and well-being of animals and specifying plans to rescue and welcome oxen, horses, pigs, rabbits, dogs, cats, birds, fish, and domestic rodents. It involves everything from on-site assistance, with water, food, medication, and animal preparation (some even require sedation), to transportation and disembarkation at the destination, in temporary shelters. In the operational part, in addition to providing guidance on initial diagnosis, action plans, composition, and team meetings, the plan also defines priorities and strategies for assisting animals. The document addresses cases subject to euthanasia provided for in legislation and guides the conduct of crime scene investigations, which includes collecting corpses and biological and chemical remains, preserving the chain of custody, and maintaining the suitability of the remains from their recognition and collection until its use by the justice department as an evidence element (23).

The plan also addresses aspects pertinent to legal veterinary medicine, forensic necropsy, biosafety measures and personal protective equipment, immunization of workers and volunteers, health service waste management plan, and work zones. It also deals with a hierarchical structure for organizing the responsibilities of official bodies and their actions during the response to a disaster. The plan also describes what the documentation system for veterinary medical care should be in the routine of temporary shelters for rescued animals and indicates how to deal with the destination of domestic animals for temporary home, adoption, or reintegration with the guardian (22).

DISCUSSION

Like people, animals are also victims of disasters, and they need to receive due attention, following ethical, legal, sanitary, social, and environmental protocols. Over the course of one decade, rescue efforts were improved, and rescue techniques and procedures were developed for different animal species in different types of catastrophe situations, as well as standard operating protocols, first-aid protocols in the field, protocols for use of anesthetics in the field, and vaccine and medication protocols for each type of species affected, in addition to training teams to work on different fronts.

The disaster veterinary medicine is an emerging area with a strong humanitarian bias and requires social motivation because there are several situations that professionals face in these occurrences that require preparation and continuous training. In addition, emotional intelligence is needed to face the realities encountered in disaster situations, such as environmental destruction, extreme contexts of crisis, dangerous situations, and vulnerability involving the homeless, missing, and dead. In times of disaster, the teams involved are faced with a chaotic and complex environment, which requires coordinated and integrated action by multiple agencies, aimed at mitigating suffering and damage.

Another point to be highlighted is that after the occurrence of a series of disasters and the work of voluntary rescue teams, there has been a greater appreciation of the veterinary medicine class by society and companies, especially companies that provide services for the systemic monitoring of fauna in affected areas and are thus considering hiring veterinarians to be integrated into multidisciplinary teams.

The environmental disasters that occurred in Brazil showed the importance of professionals that act in disasters. In contexts such as large fires, landslides, floods, ruptures of tailings dams, and natural disasters (such as tornadoes and storms), veterinarians work mainly in the rescue and clinical and surgical care of animals of different species of domestic and wild fauna. However, these professionals can also form activities in the field of food security for the affected population, in pest control, and, in action planning, in integrated work of several teams involved in the affected regions, which emphasizes the interdisciplinary profile of the veterinary medicine in the concept of One Health.

The work of veterinarians in interaction with other professionals in environmental disasters proved to be effective and necessary for the rescue of animals, not only because they are part of the affected families and because animals are sentient beings but also because they are important characters in the epidemiological scenario before, during, and after a disaster has occurred. We consider that this information is essential to influence scientific priorities in this approach and give support nationally and internationally for public policies and decision-making at local and global levels for disaster preparedness in the future with a focus on the approach of EcoHealth and Planetary Health.

With the content of the National Mass Disaster Contingency Plan Involving Animals, in Brazil, it is expected that the actions of rescuing animals in situations of mass disasters can be officially recognized and incorporated into the activities of the agencies and institutions responsible for responding to crisis scenarios.

AUTHOR CONTRIBUTIONS

CS and GC contributed to the conception and design of the paper and organized the information of the presented data. GC organized the paper text. All authors revised and contributed with their professional and personal experience in the actions on the rescue of animals in the environmental disasters in Brazil, in different regions and years.

ACKNOWLEDGMENTS

We would like to thank the Disaster Animal Rescue Group [*Grupo de Resgate de Animais em Desastres* (GRAD)], the National Animal Protection and Defense Forum [*Fórum Nacional de Proteção e Defesa Animal* (FNPDA)], the Regional Council of Veterinary Medicine of the State of Minas Gerais [*Conselho Regional de Medicina Veterinária* (CRMV-MG)], the Federal Council of Veterinary Medicine [*Conselho Federal de Medicina Veterinária* (CFMV)], and the Federal Institute of Espírito Santo (Ifes) for the financial support for publication.

REFERENCES

1. Brasil. Ministério da Integração Nacional. Secretaria Nacional de Proteção e Defesa Civil. *Resposta: gestão de desastres, decretação e reconhecimento federal e gestão de recursos federais em proteção em defesa civil para resposta*. Brasília: Ministério da Integração Nacional (2017). p. 106.
2. Mata-Lima H, Alvino-Borba A, Pinheiro A, Mata-Lima A, Almeida JA. Impacto dos desastres naturais nos sistemas ambiental e socioeconômico: o que faz a diferença? *Ambient Soc.* (2013) 16:3. doi: 10.1590/S1414-753X2013000300004
3. Díaz A, Trelles S, Murillo JC. *A gestão do risco e a atenção de animais em situação de desastre*. São José: IICA (2015). p. 92.
4. Nix-Stevenson D. Human response to natural disasters. *SAGE Open.* (2013) 3:3. doi: 10.1177/2158244013489684
5. Arculeo C, Khorram-Manesh A. Functions needed in disaster management. In: Khorram-Manesh A, editor. *Handbook of*

Disaster and Emergency Management. Gothenburg: Kompendiet (2017). p. 30–34.

6. Chen L, Miller-Hooks E. Optimal team deployment in urban search and rescue. *Transport Res B Meth.* (2012) 46:8. doi: 10.1016/j.trb.2012.03.004
7. Lisniak A, Arculeo C. Search and rescue (SAR), and safety and security. In: Khorram-Manesh A, editor. *Handbook of Disaster and Emergency Management*. Gothenburg: Kompendiet (2017). p. 97–103.
8. Confalonieri UEC, Marinho, DP. Mudança Climática Global e Saúde: perspectivas para o Brasil. *Revista Multiciência*. (2007) 8:48–64.
9. Alvim EMEF, Gomes LB, Jacinto ST, Bastos ALF, Miranda CMS, Machado IBA. Necessidade de capacitar profissionais especializados motivou guia. *Revista CFMV*. (2020) 85:11–6.
10. Nunes VFP, Biondo AW. A medicina veterinária de desastres em Mariana e Brumadinho: importância da inclusão de animais nos planos de emergência. *Clín Vet.* (2019) 139:12–16.
11. Gabriel FÂ, Hauser-Davis RA, Soares L, Mazzuco ACA, Rocha RCC, Saint Pierre TD, et al. Contamination and oxidative stress biomarkers in estuarine fish following a mine tailing disaster. *PeerJ.* (2020) 8:e10266. doi: 10.7717/peerj.10266
12. Santos FLM. *Área queimada – Pantanal 2020*. Laboratório de Aplicações de Satélites Ambientais da Universidade Federal do Rio de Janeiro. Available online at: https://lasa.ufrj.br/noticias/area-queimada-pantanal-2020/ (accessed October 27, 2020).
13. Couto RM, Brandespim DF. A review of the One Health concept and its application as a tool for policy-makers. *Int J One Health.* (2020) 6:1. doi: 10.14202/IJOH.2020.83-89
14. Pinto AJW, Fonseca LF. A eutanásia dos animais por arma de fogo em Brumadinho. *Clín Vet.* (2019) 141:12–5.
15. Furtado JR. *Gestão de desastres e ações de recuperação*. Florianópolis: UFSC (2014). p. 242.
16. Hréckovski B, Khorram-Manesh A. Information colleting and sharing. In: Khorram-Manesh A, editor. *Handbook of Disaster and Emergency Management*. Gothenburg: Kompendiet (2017) p. 77–81.
17. Castro LM, Junior CZ, Miranda CMS, Nunes VFP, Nascimento AAT. O trabalho das equipes de diagnóstico e reconhecimento perante os desastres envolvendo animais. *Clín Vet.* (2020) 146:12–9.
18. Bastos AL. A atuação dos médicos-veterinários nos desastres. *Clín Vet.* (2019) 140:12–6.
19. Sobral A, Freitas CM, Andrade EV, Lyra GFD, Mascarenhas MS, Alencar MRF, Castro RAL, França RF. Desastres naturais – sistemas de informação e vigilância: uma revisão da literatura. *Epidemiologia e Serviços de Saúde*. (2010) 19:4. doi: 10.5123/S1679-49742010000400009
20. Arruda EC, Araujo GD, Sousa MG. Plano de ação para resgate de animais em desastres ambientais. *Revista MV&Z*. (2015) 13:68.
21. CFMV—Conselho Federal de Medicina Veterinária. Decisão N° 1, de 2 outubro de 2020. *Diário Oficial da União*. (2020) 191:1 p. 244. Available online at: https://www.in.gov.br/en/web/dou/-/decisao-n-1-de-2-outubro-de-2020-281066500 (accessed October 5, 2020).
22. Gomes LB, Reis ST, Atayde IB, Bastos ALF, Miranda CMS. *Plano Nacional de Contingência de Desastres em Massa Envolvendo Animais*. Brasília: CFMV (2020). p. 105.
23. CFMV. Prevenção e ação no resgate de animais e na preservação da biodiversidade. *Revista CFMV*. (2020) 85:8–10.
24. Castro LM, Junior CZ, Miranda CMS, Barreto EFS. O suporte técnico da medicina veterinária de desastres na força-tarefa das enchentes no estado do Espírito Santo. *Clín Vet.* (202) 145:12–9.

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Public Health

OPINION
published: 07 May 2021
doi: 10.3389/fpubh.2021.648940

mcr-1 Gene in Latin America: How Is It Disseminated Among Humans, Animals, and the Environment?

Silvia Adriana Mayer Lentz[1,2], *Tanise Vendruscolo Dalmolin*[3], *Afonso Luís Barth*[4] *and Andreza Francisco Martins*[1,2,4]*

[1] *Programa de Pós Graduação em Microbiologia Agrícola e Do Ambiente, Universidade Federal Do Rio Grande Do Sul, Porto Alegre, Brazil,* [2] *Laboratório de Microbiologia Aplicada, Instituto de Ciências Básicas da Saúde, Universidade Federal Do Rio Grande Do Sul, Porto Alegre, Brazil,* [3] *Faculdade de Saúde, Departamento de Farmácia, Universidade de Brasília (UnB), Brasília, Brazil,* [4] *Laboratório de Pesquisa em Resistência Bacteriana (LABRESIS), Hospital de Clínicas de Porto Alegre, Porto Alegre, Brazil*

Keywords: ***mcr-1*** **gene, IncX4 plasmid type, colistin resistance, Latin America, antimicrobial resistance**

OPEN ACCESS

Edited by:
Swaminath Srinivas,
University of Illinois at Urbana-Champaign, United States

Reviewed by:
Ridwan Bin Rashid,
State University of Bangladesh, Bangladesh

***Correspondence:**
Andreza Francisco Martins
andrezafm20@gmail.com

Specialty section:
This article was submitted to Planetary Health, a section of the journal Frontiers in Public Health

Received: *02 January 2021*
Accepted: *22 February 2021*
Published: *07 May 2021*

Citation:
Lentz SAM, Dalmolin TV, Barth AL and Martins AF (2021) mcr-1 Gene in Latin America: How Is It Disseminated Among Humans, Animals, and the Environment? Front. Public Health 9:648940. doi: 10.3389/fpubh.2021.648940

INTRODUCTION

In the last decade, polymyxins have been reintroduced in the therapeutic arsenal to treat severe infections by carbapenem-resistant Enterobacterales. At that time, reports of polymyxin resistance were all due to chromosomal mutations (1). These mechanisms included (i) modifications of the lipopolysaccharides (LPSs) moiety via the addition of cationic groups; (ii) mutations that lead to the loss of the LPS; (iii) porin mutations and overexpression of efflux pump systems; (iv) overproduction of capsular polysaccharide (CPS) in some Gram-negative bacteria (GNB) that hide the polymyxin-binding sites and the release of CPS-trapping polymyxins; and (v) enzymatic inactivation of polymyxins (2). Although some chromosomal resistance mechanisms have been studied since the 1960's, it was in the late 1990's, after the reintroduction of polymyxins in the therapeutic arsenal, that this problem became more important (3). In fact, this information is supported by the first report of colistin resistance among *Acinetobacter baumannii* clinical isolates from the Czech Republic in 1999 and *Klebsiella pneumoniae* from Athens in 2004 (4).

However, in 2015, the *mcr-1* gene, associated with IncI2-type plasmid, was identified in *Escherichia coli* resistant to colistin obtained from food animals and humans in China (1). This finding promoted a great concern in the international scientific community since the last therapeutic option to treat serious infections by multidrug-resistant GNB could be exhausted. With the horizontal transfer, the rapid spread of the *mcr-1* gene would be inevitable.

The *mcr-1* gene carried by different plasmid types has already been identified in all five continents from different sources and hosts (1, 5). Surprisingly, Shen and colleagues, in a retrospective study, characterized the early occurrence of the *mcr-1* gene in chicken isolates from 1980's (6).

So far, a total of 10 different variants (7) of the *mcr* gene have been described mainly among the Enterobacterales, but with the *mcr-1* gene remaining the most prevalent (1). To date, the sequences of 30 *mcr-1* mutations (*mcr-1.2* to *mcr-1.30*) have already been deposited in the GenBank database, differing from *mcr-1* by one or few amino acids. Besides that, 10 *mcr* gene variants (*mcr-1* to *mcr-10*) were deposited, with amino acid identity ranging from 31 to 83% (8). These variants were identified at the beginning in Enterobacterales isolates, including *E. coli* (*mcr-1*, *mcr-2*, and *mcr-3* genes), *Salmonella enterica* (*mcr-4*, *mcr-5* and *mcr-9* genes), *K. pneumoniae* (*mcr-7* and *mcr-8* genes), and *Enterobacter roggenkampii* (*mcr-10* gene). The exception is due to *mcr-6* gene that was first identified in *Moraxella* spp. After that, some variants were identified in non-fermenter

Gram-negative rods, as *Acinetobacter* spp. (*mcr-1* and *mcr-4*) and *Pseudomonas* spp. (*mcr-1* only) (9, 10).

In general, the isolates carrying *mcr* genes were first isolated from animals such as pigs (*mcr-1*, *mcr-2*, *mcr-3*, *mcr-4*, *mcr-6*, and *mcr-8* genes) and chickens (*mcr-5* and *mcr-7* genes), but *mcr-9* and *mcr-10* genes were identified, for the first time, from human patients (8).

EPIDEMIOLOGY OF POLYMYXIN RESISTANCE

The resistance to polymyxins was attributed mainly to chromosomal mutations and is rare in human clinical isolates (0.67–1.6%) (11). Nevertheless, this differs among bacteria species, being higher in *K. pneumoniae* and *A. baumannii* (20–80%) (4) in contrast to lower rates in *E. coli* (0.2–0.6%) (11).

The polymyxin resistance rate associated to plasmid, as *mcr-1*, is also low in humans (∼1%) (4). On the other hand, according to a large US surveillance study, the association between *mcr-1* and other antibiotic resistance genes, such as extended-spectrum β-lactamase (ESBL) and carbapenemases, may reach 32% of prevalence in *K. pneumoniae* (11). Regarding the mortality associated with infections caused by colistin-resistant isolates in humans, the rate is variable, and it is higher in critically ill patients (30–37%) including those previously exposed to colistin (4). The mortality rate may reach 100% in patients with nosocomial infections caused by pan–drug-resistant *K. pneumoniae.*

It is important to emphasize that the prevalence of *mcr-1* gene is higher among production animals, mainly in pig and chicken isolates (5). The data show colistin resistance rates of ∼70% in *E. coli* isolates from China and ∼90% among Enterobacterales in some European countries (8). So, these data corroborate with the scientific evidence that the worldwide spread of the *mcr-1* gene is mainly associated with the large amounts of colistin use in production animals, and its emergence is a particular threat to public health as colistin is considered the last-resort antimicrobial for treatment of severe human infections, and its use in livestock production contributes to emerging resistance globally (1).

mcr-1 IN LATIN AMERICA

In Latin America, a systematic review analysis showed that the prevalence of *mcr-1* gene is higher in isolates from animals (8.7%) than in food (5.4%) and humans (2.0%) (12). To the best of our knowledge, the first reports of *mcr-1* gene in Latin America dated from July and October 2012 when this gene was identified in *E. coli* isolates from two inpatients in different hospitals in Argentina (**Table 1**) (13). Patients presented neurological disease and diabetes, and the *mcr-1*–positive isolates were obtained from blood and urine, respectively. In this study, the authors evaluated the presence of the *mcr-1* gene in 87 colistin-resistant clinical human isolates from 2008 to 2016 (28 *E. coli*, 19 *K. pneumoniae*, 36 of other members of the Enterobacterales, and 4 non-fermenter Gram-negative rods), and nine isolates of *E. coli* were *mcr-1* positive. These isolates were associated with human infections, mainly in males, and the average age of the patients was 68.5 years. All *mcr-1*–positive *E. coli* isolates were genetically unrelated as determined by pulsed-field gel electrophoresis, and the resistance mechanism was horizontally transferable by conjugation (13). Still, in 2012, other studies reported *mcr-1* harboring *E. coli* recovered from Kelp Guls in Argentina (14) and from swine in Brazil (**Table 1**) (15).

Since 2012, the *mcr-1* gene has already been identified in bacteria from humans, animals, animal food products, and environmental sources in different countries in Latin America, including Brazil (15), Bolivia (16), Colombia (17), Chile (18), Uruguay (19), Paraguay (20), Peru (21), Mexico (22), Venezuela (23), and Ecuador (24). Brazil is the country with the highest number of *mcr-1*–positive bacteria reported in Latin America mainly from bacterial isolates obtained from poultry rectal swabs (15) (**Table 1**).

It is important to consider that Brazil is the fourth largest pork producer and exporter and the largest chicken meat exporter in the world, which could contribute to the high prevalence of the *mcr-1* gene in this country (25). As in other countries, the colistin was extensively used in Brazil as a growth promoter for many years. In 2016, the government published restrictions on the use of colistin in animal production (1, 26), which came into force in 2018. However, the use of colistin to treat or prevent infections in veterinary medicine including animal productions is still allowed.

E. coli is the most common species harboring the *mcr-1* gene in Latin America countries. However, many other Enterobacterales members such as *K. pneumoniae, Salmonella* spp., *Citrobacter* spp., and *Enterobacter* spp. were also reported as positive for the *mcr-1* gene (17, 27). In addition to *mcr-1*, other variants of the gene were reported rarely in Latin America, such as *mcr-3*, *mcr-5*, *mcr-7*, and *mcr-9* (28–30).

GENETIC CONTEXT AND DISSEMINATION OF *mcr-1* GENE

E. coli isolates harboring *mcr-1* gene belong to different sequence types (STs) (31, 32) (**Table 1**), indicating that the dissemination of the *mcr-1* gene is associated with different clonal strains (1). Loayza-Villa and colleagues investigated the relationship between an *E. coli* carrying *mcr-1* recovered from the gastrointestinal tract of a boy and an *mcr-1*–positive *E. coli* from fecal samples and rectal/cloacal swabs from his domestic animals. *E. coli* strains from domestic animals and from the boy were different; however, all plasmids harboring the *mcr-1* gene shared 90% nucleotide identity and a highly conserved backbone, supporting the idea of horizontal dissemination of the *mcr-1* gene (32).

In Latin America, the *E. coli* belonging to CC10 clonal complex, known as the largest human clonal complex, was the most reported in previous studies, including the ST744 and ST10 (1, 17, 22, 33). *E. coli* CC10 strains are widely disseminated among humans, animals, meat products, and environmental sources (34, 35) and are designated as multidrug-resistant strains carrying frequently ESBL, among others (5, 31).

The *mcr-1* gene is carried by a wide range of conjugative and non-conjugative plasmid types, including IncX3, IncX4, an

TABLE 1 | Summary of mainly studies reporting *mcr-1* gene in Latin America.

Period of the study	Country	Source of Isolate	Total Isolates (*mcr*-carried)	Species	Plasmid Type	Sequence Type (ST)	Genetic Context	References
2000–2016	Brazil	Fecal samples-chicken and swine (Production Animals)	515 (16)	*E. coli*	–	–	–	(15)
2002–2016	Colombia	Urine vaginal secretion blood stool tissue right toe leg secretion abdomen abscess (Human)	513 (12)	*E. coli* *S. enterica* Typhimurium *K. pneumoniae*	IncP-1 IncFII IncHI1 IncH	*E. coli* (ST10, ST37, ST101, ST744, ST1263, ST3056, and ST6627) *S.* Typhimurium (ST34) *K. pneumoniae* (ST307)	IS*Apl1*-*mcr-1*-*pap2* (IncP-1) *mcr-1*-*pap2* (IncP-1)	(17)
2008–2016	Argentina	Urine, blood, abdomen, abscess, bone (Human)	87 (9)	*E. coli*	–	–	–	(13)
2012	Argentina	Fecal samples - Kelp gulls penguin (Wild Animal)	50 (5)	*E. coli*	IncI2	ST101 and ST744	IS*Apl1*-*mcr-1*	(14)
2012–2018	Argentina	Urine, blood, other samples (Human)	192 (192)	*E. coli*	IncHI2 IncX4	ST10, ST156, ST354, ST8492, ST5208	–	(37)
2013	Bolivia	Potatoes (Food)	83 (1)	*C. braakii*	IncI2	–	–	(16)
2013	Argentina	Fecal samples–Chicken (Production Animals)	10 (10)	*E. coli*	IncI2	ST155 (CC10: ST10, ST1141 and ST1286), ST617, ST10, ST410, ST1011, ST1408	IS*Apl1*-*mcr-1.5*-*pap2*- IS*Apl1*	(33)
2013–2014	Ecuador	Feces–chicken (Production Animals)	176 (6)	*E. coli*	–	–	–	(24)
2013–2016	Brazil	Meat Poultry (Food)	60 (2)	*Salmonella enterica* serovar Schwarzengrund	IncX4	ST96	*parA* and hypothetical protein upstream *mcr-1* and *pap2* downstream	(44)
2013–2017	Chile	Urine (Human)	13 (1)	*E. coli*	IncI2	ST4204 (CC10)	*mcr-1* was delimited upstream by a gene that encodes a *pap2* protein and downstream by a relaxase-encoding gene (*nikB*)	(18)
2014	Argentina	Clinical samples - dogs and cats (Pets)	54 (1)	*E. coli*	IncI2	ST770	*mcr-1* was delimited upstream by *nikB* gene which encodes a relaxase and *pap2* downstream	(31)
2014–2017	Brazil	Pork carcasses (Food)	490 (8)	*S. enterica* serovar Typhimurium	IncX4	ST19 ST4556 ST50	*mcr-1* was delimited upstream by IS*26* and hypothetical protein and *pap2* downstream	(26)
2015	Venezuela	Fecal samples (Human and Animal)	93 (2)	*E. coli*	IncI2	ST452 and ST19	Absence of IS*Apl1*	(23)
2015	Mexico	Swine stool samples (Production Animal)	1 (1)	*E. coli*	Incp0111	ST744	IS*Apl1* upstream *mcr-1* gene	(22)

(Continued)

TABLE 1 | Continued

Period of the study	Country	Source of Isolate	Total Isolates (*mcr*-carried)	Species	Plasmid Type	Sequence Type (ST)	Genetic Context	References
2015–2016	Brazil	Rectal swab and urine (Human)	140 (2)	*E. coli*	IncX4	ST206 and ST354	*mcr-1* was delimited upstream by IS*26* and hypothetical protein and *pap2* downstream	(46)
2016	Brazil	Seawater (Environment)	11 (3)	*E. coli*	IncX4	–	–	(36)
2016	Ecuador	Fecal swabs and soil fecal from chicken and two dogs (Domestic Animals)	42 (3)	*E. coli*	IncI2	ST3941, ST1630, ST2170	*mcr-1* was delimited upstream by *nikB* gene and *pap2* downstream	(32)
2016	Brazil	Rectal swab (Human)	3 (3)	*E. coli* and *K. pneumoniae*	IncX4	*E. coli* ST744 and *K. pneumoniae* ST101	–	(38)
2016	Bolivia	Fecal samples (Human)	337 (173)	*E. coli*, *C. europaeus*, *E. hormaechei*	IncI2 and IncHI1 (*E. coli*); *Citrobacter* and *Enterobacter* (IncI2)	*E. coli* (ST48, ST744, ST10, ST206, ST2705, ST2936, ST1286, ST7,570, ST69, ST10, ST117, ST711, ST7571, ST3056)	*mcr-1-pap* (IncI2) *mcr-1.5-pap* IS*Apl1* (IncHI1) IS*Apl1-mcr-1-pap*-IS*Apl1* (IncHI1)	(27)
2016–2017	Paraguay	Urine and feces (Human)	150 (7)	*K. pneumoniae, E. coli,* and *S.* Schwarzengrund	–	–	–	(20)
2017	Brazil	Water Sample from a mangrove (Environment)	1 (1)	*E. coli*	IncX4	–	–	(39)
2017	Uruguay	Blood, rectal swab, and urine (Human)	3 (3)	*E. coli*	IncI2 e IncX4	ST10, ST93, and ST5442	–	(19)
2017	Peru	Urine (Human)	10 (7)	*E. coli*	–	–	–	(21)
2019	Brazil	Fecal sample and Water from Zoo (Wild Animal and Environment)	27 (5)	–	–	–	–	(28)
2020	Brazil	Blood, urine, and peritoneal fluid (Human)	100 (2)	*E. coli* and *K. pneumoniae*	IncX4	ST471/ST410 (*E. coli*) and ST15 (*K. pneumoniae*)	–	(29)

–: No data.

IncX3–X4 hybrid, IncH1, IncHI1, IncHI2, IncP, IncI2, IncF, IncFII, an IncI2–IncFIB hybrid, and IncY (5). The *mcr-1* gene can also be integrated into the chromosome of some strains (17). However, in Latin America, only four plasmids have been described so far: IncX4 (36), IncP (22), IncI2 (31), and IncHI2 (37), of which the IncX4 plasmid is the most frequent in Brazil (38, 39) (**Table 1**). There is a clear association between the IncX4 plasmids and the insertion sequences associated with the dissemination of the *mcr-1* gene (40).

Plasmid analysis has revealed that the insertion sequence IS*Apl1* (which belongs to the IS30 family transposase), in a composite transposon (IS*Apl1*-*mcr-1*-IS*Apl1*), is usually present in IncHI2-type plasmids (size of 200 kb), being either present or absent in IncI2-type plasmids (60 kb), and completely absent in IncX4-type plasmids (30 kb) (**Table 1**).

The role of IS*Apl1* in the mobilization of the *mcr-1* gene was demonstrated *in vitro* by transposition. It was suggested that the recombination events associated with mobilization of the *mcr-1* gene were initially mediated by two copies of IS*Apl1* from an unknown progenitor to a plasmid and subsequently transferred to Enterobacterales (41).

Besides that, according to Snesrud et al., the presence of a single or two copies of IS*Apl1* indicates a recent acquisition of the *mcr-1* gene, whereas the absence of this insertion sequence could be correlated with the adaptation of the *mcr-1* gene to a new host (41).

The regulation mechanism of *mcr-1* gene expression is complex and remains unknown. In general, the gene expression is controlled by its promoter and the corresponding activators and/or inhibitors. Zhang et al. suspect that genes encoding activators and/or inhibitors in the host chromosome may affect the expression of the *mcr-1* gene found on plasmids IncX4 and other plasmids. They may vary expressively in unlike genetic backgrounds of the different strains and/or *mcr-1*–harboring plasmids, despite that their promoters are remarkably similar (42).

Although the mobility and dissemination of the *mcr-1* gene are associated with IS*Apl1* and the *pap2* gene in most plasmid types (43), the genetic context of the IncX4 plasmid type, in Latin America, is different. This context is characterized by lacking the IS*Apl1*, but it preserves the *pap2* sequence and a hypothetical protein (hp) around the *mcr-1* gene (26, 44). What would be the explanation for that?

Snesrud et al. analyzed the genetic environment of the *mcr-1* gene associated or not with IS*Apl1* and concluded that the target site duplications generated by IS*Apl1* transposition are present even in lack of the IS*Apl1*. This result suggests that the mechanism to mobilize the *mcr-1* gene is the same as that observed in other plasmids, and after that, the loss of the insertion sequence by recombination events in IncX4 occurs (45).

Furthermore, the IS26 mobile element upstream to the *mcr-1* gene has been also associated with IncX4 plasmid types in Brazil, but there are no other reports in Latin America (26, 46) (**Table 1**). This Insertion Sequence (IS) plays an important role in the dissemination and evolution of the antimicrobial resistance genes on plasmids, including colistin resistance genes (1).

DISCUSSION

In veterinary medicine, colistin is mainly administrated in pigs and poultry production, for prophylaxis or treatment. The spread of colistin resistance may lead to treatment failure, as well as increase the pathogen transmission reach with quality and economic loss in production animals.

Strong scientific evidence indicates that the *mcr-1* gene might have originated from animals because (i) colistin has been used extensively for decades in veterinary practices; (ii) *mcr-1* gene was largely identified in several animals and animal food products; (iii) the identification of the *mcr-1* gene in *E. coli* isolate recovered before 1980 in China suggests that the emergence of this gene may be linked to the use of colistin as a growth promoter in the poultry industry; and (iv) genetic features of *mcr-1* gene associated with IS*Apl1* were first identified in *Actinobacillus pleuropneumoniae*, a common animal pathogen (43), which could be involved in recombination events leading to the mobilization of the *mcr-1* cassette.

Finally, a recent study has demonstrated that when colistin is banned from use in animal feed, there was a significant decrease of the *mcr-1* gene prevalence in most sources, including pig farms, food, and environment samples (47). Given that the production animals can be a reservoir for *mcr-1* gene and its dissemination can occur by food and environment, all countries should apply surveillance, monitoring, and restrictive measures to polymyxins use. In Latin America, Brazil, and Argentina (1) have already banned the use of colistin as a growth promoter, but the impact of this measure has not been evaluated yet.

The problem of antimicrobial resistance is related to the use and abuse of antibiotics in humans, animals, and the environment. Besides that, the *mcr-1* gene is disseminated mainly by *E. coli* clones, with a high capacity to survive in different ecological niches, some of them with pandemic and epidemic potential. So, it seems clear that the One Health approach should be adopted to integrate veterinary and human medicine to address antimicrobial resistance.

AUTHOR CONTRIBUTIONS

SAML, TVD, and AFM: conception of the opinion, collected data, and wrote the paper. ALB and AFM: reviewed and edited. All authors contributed to the article and approved the submitted version.

FUNDING

This study was funded by National Institute of Antimicrobial Resistance Research - INPRA (MCTI/CNPq/CAPES/FAPs n° 16/2014). SAML were supported by a grant from the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES).

REFERENCES

1. Anyanwu MU, Jaja IF, Nwobi OC. Occurrence and characteristics of mobile colistin resistance (*Mcr*) gene-containing isolates from the environment: a review. *Int J Environ Res Public Health.* (2020) 17:1028. doi: 10.3390/ijerph17031028
2. Olaitan AO, Morand S, Rolain J-M. Mechanisms of polymyxin resistance: acquired and intrinsic resistance in bacteria. *Front Microbiol.* (2014) 5:643. doi: 10.3389/fmicb.2014.00643
3. Kai J, Wang S. Recent progress on elucidating the molecular mechanism of plasmid-mediated colistin resistance and drug design. *Int Microbiol.* (2020) 23:355–66. doi: 10.1007/s10123-019-00112-1
4. Li Z, Cao Y, Yi L, Liu J-H, Yang Q. Emergent polymyxin resistance: end of an Era? *Open forum Infect Dis.* (2019) 6:ofz368. doi: 10.1093/ofid/ofz368
5. Quiroga C, Nastro M, Di Conza J. Current scenario of plasmid-mediated colistin resistance in Latin America. *Rev Argent Microbiol.* (2019) 51:93–100. doi: 10.1016/j.ram.2018.05.001
6. Shen Z, Wang Y, Shen Y, Shen J, Wu C. Early emergence of *mcr-1* in *Escherichia coli* from food-producing animals. *Lancet Infect Dis.* (2016) 16:293. doi: 10.1016/S1473-3099(16)00061-X
7. Wang C, Feng Y, Liu L, Wei L, Kang M, Zong Z. Identification of novel mobile colistin resistance gene *mcr-10*. *Emerg Microbes Infect.* (2020) 9:508–16. doi: 10.1080/22221751.2020.1732231
8. Shen Y, Zhang R, Schwarz S, Wu C, Shen J, Walsh TR, et al. Farm animals and aquaculture: significant reservoirs of mobile colistin resistance genes. *Environ Microbiol.* (2020) 22:2469–84. doi: 10.1111/1462-2920.14961
9. Martins-Sorenson N, Snesrud E, Xavier DE, Cacci LC, Iavarone AT, McGann P, et al. A novel plasmid-encoded *mcr-4.3* gene in a colistin-resistant *Acinetobacter baumannii* clinical strain. *J Antimicrob Chemother.* (2020) 75:60–4. doi: 10.1093/jac/dkz413
10. Caselli E, D'Accolti M, Soffritti I, Piffanelli M, Mazzacane S. Spread of *mcr-1*-driven colistin resistance on hospital surfaces, Italy. *Emerg Infect Dis.* (2018) 24:1752–3. doi: 10.3201/eid2409.171386
11. Sherry N, Howden B. Emerging gram negative resistance to last-line antimicrobial agents fosfomycin, colistin and ceftazidime-avibactam–epidemiology, laboratory detection and treatment implications. *Expert Rev Anti Infect Ther.* (2018) 16:289–306. doi: 10.1080/14787210.2018.1453807
12. Mendes Oliveira VR, Paiva MC, Lima WG. Plasmid-mediated colistin resistance in Latin America and Caribbean: a systematic review. *Travel Med Infect Dis.* (2019) 31:101459. doi: 10.1016/j.tmaid.2019.07.015
13. Rapoport M, Faccone D, Pasteran F, Ceriana P, Albornoz E, Petroni A, et al. First description of *mcr-1*-mediated colistin resistance in human infections caused by *Escherichia coli* in Latin America. *Antimicrob Agents Chemother.* (2016) 60:4412–3. doi: 10.1128/AAC.00573-16
14. Liakopoulos A, Mevius DJ, Olsen B, Bonnedahl J. The colistin resistance *mcr-1* gene is going wild. *J Antimicrob Chemother.* (2016) 71:2335–6. doi: 10.1093/jac/dkw262
15. Fernandes MR, Moura Q, Sartori L, Silva KC, Cunha MP, Esposito F, et al. Silent dissemination of colistin-resistant *Escherichia coli* in South America could contribute to the global spread of the *mcr-1* gene. *Eurosurveillance.* (2016) 21:30214. doi: 10.2807/1560-7917.ES.2016.21.17.30214
16. Sennati S, Di Pilato VD, Riccobono E, Maggio TD, Villagran AL, Pallecchi L, et al. *Citrobacter braakii* carrying plasmidborne *mcr-1* colistin resistance gene from ready-to-eat food from a market in the Chaco region of Bolivia. *J Antimicrob Chemother.* (2017) 72:2127–9. doi: 10.1093/jac/dkx078
17. Saavedra SY, Diaz L, Wiesner M, Correa A, Arévalo SA, Reyes J, et al. Genomic and molecular characterization of clinical isolates of enterobacteriaceae harboring *mcr-1* in Colombia, 2002 to 2016. *Antimicrob Agents Chemother.* (2017) 61:e00841–17. doi: 10.1128/AAC.00841-17
18. Gutiérrez C, Zenis J, Legarraga P, Cabrera-Pardo JR, García P, Bello-Toledo H, et al. Genetic analysis of the first *mcr-1* positive *Escherichia coli* isolate collected from an outpatient in Chile. *Brazil J Infect Dis.* (2019) 23:203–6. doi: 10.1016/j.bjid.2019.05.008
19. Papa-Ezdra R, Grill Diaz F, Vieytes M, García-Fulgueiras V, Caiata L, Ávila P, Brasesco M, et al. First three *Escherichia coli* isolates harbouring *mcr-1* in Uruguay. *J Glob Antimicrob Resist.* (2020) 20:187–90. doi: 10.1016/j.jgar.2019.07.016
20. Melgarejo Touchet N, Martínez M, Franco R, Falcón M, Busignani S, Espínola C, et al. Plasmid-mediated colistin resistance gene *mcr-1* in Enterobacteriaceae in Paraguay. *Rev Salud Publica Del Paraguay.* (2018) 8:44–8. doi: 10.18004/rspp.2018.junio.44-48
21. Ugarte Silva RG, Olivo López JM, Corso A, Pasteran F, Albornoz E, Sahuanay Blácido ZP. Resistencia a colistín mediado por el gen *mcr-1* identificado en cepas de *Escherichia coli* y *Klebsiella pneumoniae*. Primeros reportes en el Perú. *An Fac Med.* (2018) 79:213. doi: 10.15381/anales.v79i3.15313
22. Garza-Ramos U, Tamayo-Legorreta E, Arellano-Quintanilla DM, Rodriguez-Medina N, Silva-Sanchez J, Catalan-Najera J, et al. Draft genome sequence of a multidrug- and colistin-resistant *mcr-1*-producing *Escherichia coli* isolate from a swine farm in Mexico. *Genome Announc.* (2018) 6:e00102–18. doi: 10.1128/genomeA.00102-18
23. Delgado-Blas JF, Ovejero CM, Abadia-Patiño L, Gonzalez-Zorn B. Coexistence of *mcr-1* and blaNDM-1 in *Escherichia coli* from Venezuela. *Antimicrob Agents Chemother.* (2016) 60:6356–8. doi: 10.1128/AAC.01319-16
24. Vinueza-Burgos C, Ortega-Paredes D, Narváez C, De Zutter L, Zurita J. Characterization of cefotaxime resistant *Escherichia coli* isolated from broiler farms in Ecuador. *PLoS ONE.* (2019) 14:e0207567. doi: 10.1371/journal.pone.0207567
25. Associação Brasileira de Proteína Animal. *Relatório Anual*. (2020). Available online at: http://abpa-br.org/wp-content/uploads/2020/05/abpa_relatorio_anual_2020_portugues_web.pdf (accessed November 20, 2020).
26. Rau RB, De Lima-Morales D, Wink PL, Ribeiro AR, Barth AL. Salmonella enterica *mcr-1* positive from food in Brazil: detection and characterization. *Foodborne Pathog Dis.* (2020) 17:202–8. doi: 10.1089/fpd.2019.2700
27. Giani T, Sennati S, Antonelli A, Di Pilato V, di Maggio T, Mantella A, et al. High prevalence of carriage of *mcr-1*-positive enteric bacteria among healthy children from rural communities in the Chaco region, Bolivia, september to october 2016. *Euro Surveill.* (2018) 23:1800115. doi: 10.2807/1560-7917.ES.2018.23.45.1800115
28. dos Santos LDR, Furlan JPR, Ramos MS, Gallo IFL, de Freitas LVP, Stehling EG. Co-occurrence of *mcr-1*, *mcr-3*, *mcr-7* and clinically relevant antimicrobial resistance genes in environmental and fecal samples. *Arch Microbiol.* (2020) 202:1795–800. doi: 10.1007/s00203-020-01890-3
29. Rocha IV, dos Santos Silva N, das Neves Andrade CA, de Lacerda Vidal CF, Leal NC, Xavier DE. Diverse and emerging molecular mechanisms award polymyxins resistance to Enterobacteriaceae clinical isolates from a tertiary hospital of Recife, Brazil. *Infect Genet Evol.* (2020) 85:104584. doi: 10.1016/j.meegid.2020.104584
30. Faccone D, Martino F, Albornoz E, Gomez S, Corso A, Petroni A. Plasmid carrying *mcr-9* from an extensively drug-resistant NDM-1-producing *Klebsiella quasipneumoniae* subsp. *quasipneumoniae* clinical isolate. *Infect Genet Evol.* (2020) 81:104273. doi: 10.1016/j.meegid.2020.104273
31. Rumi M V, Mas J, Elena A, Cerdeira L, Muñoz ME, Lincopan N, et al. Co-occurrence of clinically relevant β-lactamases and MCR-1 encoding genes in *Escherichia coli* from companion animals in Argentina. *Vet Microbiol.* (2019) 230:228–34. doi: 10.1016/j.vetmic.2019.02.006
32. Loayza-Villa F, Salinas L, Tijet N, Villavicencio F, Tamayo R, Salas S, et al. Diverse *Escherichia coli* lineages from domestic animals carrying colistin resistance gene *mcr-1* in an Ecuadorian household. *J Glob Antimicrob Resist.* (2020) 22:63–7. doi: 10.1016/j.jgar.2019.12.002
33. Dominguez JE, Faccone D, Tijet N, Gomez S, Corso A, Fernández-Miyakawa ME, et al. Characterization of *Escherichia coli* carrying *mcr-1*-plasmids recovered from food animals from Argentina. *Front Cell Infect Microbiol.* (2019) 9:41. doi: 10.3389/fcimb.2019.00041
34. Manges AR, Harel J, Masson L, Edens TJ, Portt A, Reid-Smith RJ, et al. Multilocus sequence typing and virulence gene profiles associated with *Escherichia coli* from human and animal sources. *Foodborne Pathog Dis.* (2015) 12:302–10. doi: 10.1089/fpd.2014.1860
35. Chen P-A, Hung C-H, Huang P-C, Chen J-R, Huang I-F, Chen W-L, et al. Characteristics of CTX-M extended-spectrum β-lactamase-producing *Escherichia coli* strains isolated from multiple rivers in Southern Taiwan. *Appl Environ Microbiol.* (2016) 82:1889–97. doi: 10.1128/AEM.03222-15
36. Fernandes MR, Sellera FP, Esposito F, Sabino CP, Cerdeira L, Lincopan N. Colistin-resistant *mcr-1*-positive *Escherichia coli* on public beaches, an infectious threat emerging in recreational waters. *Antimicrob Agents Chemother.* (2017) 61:e00234–17. doi: 10.1128/AAC.00234-17

37. Faccone D, Rapoport M, Albornoz E, Celaya F, De Mendieta J, De Belder D, et al. Plasmidic resistance to colistin mediated by *mcr-1* gene in *Escherichia coli* clinical isolates in Argentina: a retrospective study, 2012-2018. *Rev Panam Salud Pub.* (2020) 44:e55. doi: 10.26633/RPSP.2020.55
38. Perdigão Neto LV, Corscadden L, Martins RCR, Nagano DS, Cunha MPV, Neves PR, et al. Simultaneous colonization by *Escherichia coli* and *Klebsiella pneumoniae* harboring *mcr-1* in Brazil. *Infection.* (2019) 47:661-−4. doi: 10.1007/s15010-019-01309-2
39. Sacramento AG, Fernandes MR, Sellera FP, Muñoz ME, Vivas R, Dolabella SS, et al. Genomic analysis of MCR-1 and CTX-M-8 co-producing *Escherichia coli* ST58 isolated from a polluted mangrove ecosystem in Brazil. *J Glob Antimicrob Resist.* (2018) 15:288–9. doi: 10.1016/j.jgar.2018.10.024
40. Sun J, Fang L-X, Wu Z, Deng H, Yang R-S, Li X-P, et al. Genetic analysis of the IncX4 plasmids: implications for a unique pattern in the *mcr-1* acquisition. *Sci Rep.* (2017) 7:424. doi: 10.1038/s41598-017-00095-x
41. Snesrud E, He S, Chandler M, Dekker JP, Hickman AB, McGann P, et al. A model for transposition of the colistin resistance gene *mcr-1* by IS*Apl1*. *Antimicrob Agents Chemother.* (2016) 60:6973–6. doi: 10.1128/AAC.01457-16
42. Zhang H, Miao M, Yan J, Wang M, Tang Y-W, Kreiswirth BN, et al. Expression characteristics of the plasmid-borne *mcr-1* colistin resistance gene. *Oncotarget.* (2017) 8:107596–602. doi: 10.18632/oncotarget.22538
43. Poirel L, Kieffer N, Nordmann P. *In vitro* study of IS*Apl1*-mediated mobilization of the colistin resistance gene *mcr-1*. *Antimicrob Agents Chemother.* (2017) 61:e00127–17. doi: 10.1128/AAC.00127-17
44. Moreno LZ, Gomes VTM, Moreira J, de Oliveira CH, Peres BP, Silva APS, et al. First report of *mcr-1*-harboring *Salmonella enterica* serovar *Schwarzengrund* isolated from poultry meat in Brazil. *Diagn Microbiol Infect Dis.* (2019) 93:376–9. doi: 10.1016/j.diagmicrobio.2018.10.016
45. Snesrud E, McGann P, Chandler M. The birth and demise of the IS*Apl1-mcr-1*-IS*Apl1* composite transposon: the vehicle for transferable colistin resistance. *MBio.* (2018) 9:e02381–17. doi: 10.1128/mBio.02381-17
46. Zamparette CP, Schorner M, Campos E, Moura Q, Cerdeira L, Tartari DC, et al. IncX4 plasmid-mediated *mcr-1.1* in polymyxin-resistant *Escherichia coli* from outpatients in Santa Catarina, Southern Brazil. *Microb Drug Resist.* (2020) 26:1326–33. doi: 10.1089/mdr.2019.0203
47. Wang Y, Xu C, Zhang R, Chen Y, Shen Y, Hu F, et al. Changes in colistin resistance and *mcr-1* abundance in *Escherichia coli* of animal and human origins following the ban of colistin-positive additives in China: an epidemiological comparative study. *Lancet Infect Dis.* (2020) 20:1161–71. doi: 10.1016/S1473-3099(20)30149-3

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Public Health

ORIGINAL RESEARCH
published: 11 May 2021
doi: 10.3389/fpubh.2021.611152

Check for updates

Modeling the Potential Distribution of the Malaria Vector *Anopheles (Ano.) pseudopunctipennis* Theobald (Diptera: Culicidae) in Arid Regions of Northern Chile

Lara Valderrama [1,2], Salvador Ayala [3], Carolina Reyes [1] and Christian R. González [2,4]*

[1] Laboratorio de Entomología, Subdepartamento de Genética Molecular, Instituto de Salud Pública de Chile, Santiago, Chile, [2] Programa de Magíster en Ciencias mención Entomología, Universidad Metropolitana de Ciencias de la Educación, Santiago, Chile, [3] Departamento de Asuntos Científicos, Instituto de Salud Pública de Chile, Santiago, Chile, [4] Instituto de Entomología, Universidad Metropolitana de Ciencias de la Educación, Facultad de Ciencias Básicas, Santiago, Chile

OPEN ACCESS

Edited by:
Christina Pettan-Brewer, University of Washington, United States

Reviewed by:
Lei Xu, Tsinghua University, China
Ahmad Ali Hanafi-Bojd, Tehran University of Medical Sciences, Iran

****Correspondence:***
Lara Valderrama
lvalderrama@ispch.cl

Specialty section:
This article was submitted to Planetary Health, a section of the journal Frontiers in Public Health

Received: *28 September 2020*
Accepted: *16 March 2021*
Published: *11 May 2021*

Citation:
Valderrama L, Ayala S, Reyes C and González CR (2021) Modeling the Potential Distribution of the Malaria Vector Anopheles (Ano.) pseudopunctipennis Theobald (Diptera: Culicidae) in Arid Regions of Northern Chile. Front. Public Health 9:611152. doi: 10.3389/fpubh.2021.611152

The extreme north of Chile presents a subtropical climate permissive of the establishment of potential disease vectors. *Anopheles* (*Ano.*) *pseudopunctipennis* is distributed from the south of the United States to the north of Argentina and Chile, and is one of the main vectors of malaria in Latin America. Malaria was eradicated from Chile in 1945. Nevertheless, the vector persists in river ravines of the Arica and Tarapacá regions. The principal effect of climate change in the north of Chile is temperature increase. Precipitation prediction is not accurate for this region because records were erratic during the last century. The objective of this study was to estimate the current and the projected distribution pattern of this species in Chile, given the potential impact due to climate change. We compiled distributional data for *An.* (*Ano.*) *pseudopunctipennis* and constructed species distribution models to predict the spatial distribution of this species using the MaxEnt algorithm with current and RCP 4.5 and 8.5 scenarios, using environmental and topographic layers. Our models estimated that the current expected range of *An.* (*Ano.*) *pseudopunctipennis* extends continuously from Arica to the north of Antofagasta region. Furthermore, the RCP 4.5 and 8.5 projected scenarios suggested that the range of distribution of *An. (Ano.) pseudopunctipennis* may increase in longitude, latitude, and altitude limits, enhancing the local extension area by 38 and 101%, respectively, and local presence probability (>0.7), from the northern limit in Arica y Parinacota region (18°S) to the northern Antofagasta region (23°S). This study contributes to geographic and ecologic knowledge about this species in Chile, as it represents the first local study of *An.* (*Ano.*) *pseudopunctipennis.* The information generated in this study can be used to inform decision making regarding vector control and surveillance programs of Latin America. These kinds of studies are very relevant to generate human, animal, and environmental health knowledge contributing to the "One Health" concept.

Keywords: species distribution model, climate change, maxent, malaria, Latin America, One health

INTRODUCTION

The extreme north of Chile presents a subtropical climate, permissive of the establishment of several mosquito species. Some of these species are vectors of different pathogens affecting humans, like *Aedes* (*Ste.*) *aegypti*, *Anopheles* (*Ano.*) *pseudopunctipennis*, and *Culex* (*Cux.*) *quinquefasciatus*. *An.* (*Ano.*) *pseudopunctipennis* Theobald is distributed from the south of the United States (40°N) to the north of Argentina (30°S) and Chile along the Andes, and it extends to Venezuela and the Lesser Antilles (1, 2). It is found at altitudes from sea level up to 3,200 m. Females oviposit in river pools in mountain areas, and larvae are tolerant to wide temperature ranges and droughts because rainfall may destroy their breeding sites. Nevertheless, natural pools, rice plantations, and wetlands can also support *An.* (*Ano.*) *pseudopunctipennis*, when located in proximity to human populations (1–4). Forty-one species of *Anopheles* have been described as vectors of malaria (5), and *An.* (*Ano.*) *pseudopunctipennis* is an important vector of malaria in different countries of South America [5; (4)]. Malaria was endemic in northern Chile until 1945, the year in which the last autochthonous case of malaria was reported. However, the vector is still present, confined to natural breeding sites in riversides in Lluta Valley, Quebrada Vítor, Camarones, and Tarapacá Valley ravines in rural areas of the north of Chile [unpublished data, Laboratorio de Referencia de Entomología ISP; (6)]. Although there is no local transmission of malaria in Chile, there are, on average, 12 imported registered cases per year in the last two decades (7–9). Furthermore, there are several recent records of *An.* (*Ano.*) *pseudopunctipennis* near urban areas in Arica (18°48′33′′S latitude, 70°33′33′′O longitude) and Matilla (20°51′42′′S latitude, 69°36′14′′O longitude) [unpublished data, Unidad de Emergencias y Desastres, SEREMI de Arica y Parinacota; unpublished data, Laboratorio de Referencia de Entomología ISP; (10)]. These factors support the risk of malaria reintroduction, particularly given that the north of Chile is considered an area of immigration from the malaria endemic countries of Perú and Bolivia (11).

The north of Chile is one of the most arid regions in the world, and it is characterized as being exposed to intense solar radiation and comprised of territories at different altitudes (12). There is no consensus about climate change predictions in the north of Chile, especially regarding precipitation because record keeping has been erratic over the last century (12). Nevertheless, temperature is expected to increase by 1°C on the coast and by 4°C in the Andes mountains in the "Norte Grande" region (13). However, precipitation may decrease slightly in the north of Chile, especially in the Andean plateau (12, 14, 15), even though rainfall could increase in the Andean foothills (12). Temperature and precipitation changes and topographic characteristics of the terrain may impact the potential range of *An.* (*Ano.*) *pseudopunctipennis*, as demonstrated for other anopheline species (16–18). Important knowledge gaps remain regarding the potential effects of climate and climate change on the emergence of several vector-borne diseases in the world. Here, we provide detailed local maps of the current expected geographical range of *An.* (*Ano.*) *pseudopunctipennis* in Chile and examine possible changes in the potential distribution of this species under future climatic conditions, based on outputs of 10 global climatic models and two representative concentration pathways (RCP 4.5 and 8.5).

MATERIALS AND METHODS

Data Collection and Study Area

The study area was established from the extreme north of Chile (18°S) to the Metropolitan region (34°S) (**Figure 1**), according to the "Programa de vigilancia vectorial de culícidos del Ministerio de Salud de Chile." Occurrence data for *An.* (*Ano.*) *pseudopunctipennis* from 2009 until January 2020 were obtained from the "Programa de vigilancia vectorial de culícidos del Ministerio de Salud de Chile" "Laboratorio de Referencia de Entomología del Instituto de Salud Pública de Chile" and Cancino (10). We included all records with geographic coordinates, and filtered data to eliminate duplicate records and those with $<$ 1 km of distance between them (19). A total of 50 records were compiled: 22 from Arica y Parinacota region and 38 from Tarapacá region (**Figure 2**).

Climatic Data, Layers, and Projected Models

Data from WorldClim (20) were used to characterize current local climates, using "raster" package in R software, including 15 bioclimatic variables. Bioclimatic variables 8–9 and 18–19 were omitted from the analysis because their validity is questioned (21–23). A layer representing river proximity [given that *An.* (*Ano.*) *pseudopunctipennis* breeding sites are close to streams] and five topographic layers (altitude, slope, exposition, orientation, and flow direction), obtained from "Digital Elevation Model" (DEM) using the "elevatr" package in R software, were included to estimate the "topographic roughness index" (TRI), "topographic position index" (TPI), and "topographic wetness index" (TWI). However, we had to eliminate the Loa river from this variable because its water is brackish (24). We included another layer (human footprint) (25) because this species is a malaria vector. All variables were discharged to 1 km^2 resolution (30 s). For the projected models, we used two different climate change scenarios: RCP 4.5 and RCP 8.5. These were based on 10 global climate models covering the period from 2061 to 2080 from: ACCESS1-0 (AC) (Australian Community Climate and Earth-System Simulator), BCC-CSM1-1 (BC) (Beijing Climate Center and China Meteorological Administration), CCSM4 (CC) (National Center for Atmospheric Research), CNRM-CMIP5 (CN) (Centre National de Recherches Météorologiques and Centre Européen de Recherche et Formation Avancée en Calcul Scientifique), GFDL-CM3 (GF) (Geophysical Fluid Dynamics Laboratory), HadGEM2-ES (HE) (National Institute of Meteorological Research/Korea Meteorological Administration), INMCM4 (IN) (Institute of Numerical Mathematics Climate Model), IPSL-CMSA-LR (IP) (Institut Pierre-Simon Laplace), MIROC5 (MC) (Atmosphere and Ocean Research Institute, National Institute for Environmental Studies and Japan Agency for Marine-Earth Science, and Technology), and NorESM1-M (NO) (Norwegian Climate Centre) to 2061–2080 period of global climate models.

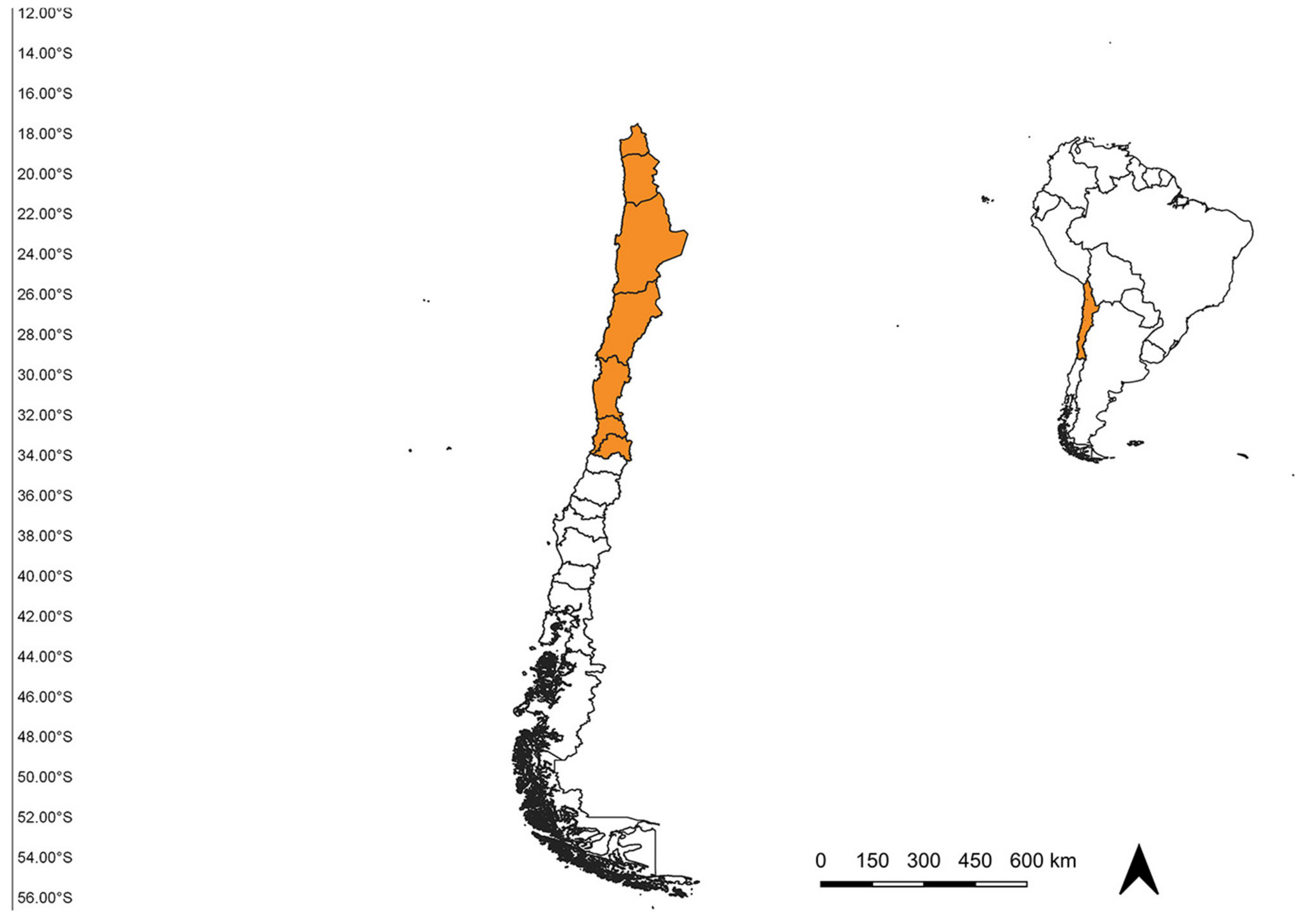

FIGURE 1 | Study area spanning from the Arica region in the north to the Metropolitan region in the south, Chile.

Species Distribution Modeling

We applied a correlation analysis and selected variables based on the variance inflation factor (VIF < 10) to avoid an over-adjustment in the models (17). We made a current species distribution model using the MaxEnt algorithm (Maxent v.3.4.1) (20) with 50 replicates (26) and 3,600 pseudoabsences (27). We selected the minimum number of variables, based on *Jackknife test*, response curve of each variable graphic and "area under the curve" value (AUC > 0.9) (18, 26, 28–30). Then, we conducted a logistic regression to explain the relation of each one of the variables with *An.* (*Ano.*) *pseudopunctipennis* presence probability (31).

Evaluation of Species Distribution Models

We selected metrics parameters [regularization multiple (RM) and function type: linear, product, quadratic, hinge, and threshold] based on the lowest "Akaike Information Criterion corrected" value (AICc) (28, 32–34) of ENMeval evaluation (35) in R software (36). We applied metrics parameters selected in the MaxEnt algorithm for current and projected conditions. We chose the best model based on the prevalence approach, average probability/suitability, sensitivity-specificity sum maximization approach, the sensitivity-specificity equality approach, and AUC value (26, 37).

Presence Probability Extension Area Calculation

We calculated the current and projected presence probability extension area based on the "maximum training sensitivity plus specificity logistic threshold."

RESULTS

According to the ENMeval evaluation, the metrics parameters selected to apply to the Maxent approach were RM = 1.5 and linear, quadratic, and product functions.

Furthermore, we chose the GF model as the best model due to prevalence approach, average probability/suitability, sensitivity-specificity sum maximization approach, sensitivity-specificity equality approach, and AUC value (**Table 1**).

According to the *Jackknife* test, the best predictor variable for the distribution of *An.* (*Ano.*) *pseudopunctipennis* in Chile was "precipitation during the wettest month" (BIO13),

FIGURE 2 | Occurrence records of *Anopheles (Ano.) pseudopuntipennis* in Chile.

second was "topographic position index" (TPI), third was "river proximity," and fourth was "annual mean temperature" (BIO1) (**Figure 3**).

Logistic regression results indicated that "BIO1" and "BIO13" were positively related to the model, while "TPI" and "river proximity" were negatively related to it. Nevertheless, "BIO13" was not significant to the model ($p = 0.752$) (**Table 2**).

All models demonstrated to have an AUC value up to 0.9, proving they have an excellent predictive performance. The current potential distribution of *An.* (*Ano.*) *pseudopunctipennis* in Chile (**Figure 4A**) showed there is a high probability of presence (orange and red areas) in several river ravines of Arica y Parinacota and Tarapacá regions, between 18°21′S and 19°37′S latitudes. This result validated the model because high presence probability areas matched with the records used for the analysis. Also, medium presence probability (green and yellow areas) extended from the north of Arica y Parinacota region (18°21′S latitude) to the north of Antofagasta region (22°28′S latitude). Low presence probability (blue area) extended from the north of Antofagasta region (21°53′S latitude) to the center of the same region (24°40′S latitude). In the future scenarios (**Figures 4B,C**), the areas of high *An.* (*Ano.*) *pseudopunctipennis* presence probability (orange and red areas) overlapped with the medium presence probability area in the current model, thus extending the zone of high presence probability from the north of Arica y Parinacota region to the north of Antofagasta region. There was a low presence probability (blue area) in "Salar de Atacama" (23°30′S latitude, 68°15′O longitude) in the current (**Figure 4A**) and RCP 4.5 scenario (**Figure 4B**), but this area increased its presence probability to medium (green area) in the RCP 8.5 scenario (**Figure 4C**). Furthermore, there is a low presence probability (blue and light blue areas) in the river ravine situated at the border of the Antofagasta region and Atacama region (between 25°23′S and 26°40′S latitudes) (**Figures 4B,C**). Comparing the presence probability extension areas in the three scenarios (current, RCP 4.5, and RCP 8.5), it increased to 38% (from 39.353 to 54.378 km^2) in the RCP 4.5 scenario, and it increased to 101% (from 39.353 to 79.299 km^2) in the RCP 8.5 model, according to the "maximum training sensitivity plus specificity logistic threshold" (0.2652).

TABLE 1 | Evaluation results to select the best model to project.

RCP	Model	Sensitivity = specificity	Sensitivity-specificity sum maximization	Predicted prevalence = observed prevalence	Predicted	Average probability	AUC
4.5	AC	0.435	0.415	0.71	0.0228	0.023	0.9962
4.5	BC	0.385	0.365	0.67	0.0201	0.0202	0.9958
4.5	CC	0.4	0.39	0.66	0.0209	0.0215	0.996
4.5	CN	0.38	0.355	0.7	0.022	0.0211	0.9953
4.5	GF	0.49	0.465	0.79	0.0256	0.0251	0.9946
4.5	HE	0.475	0.46	0.73	0.0236	0.0234	0.9961
4.5	IN	0.375	0.345	0.69	0.0214	0.0208	0.9957
4.5	IP	0.455	0.44	0.74	0.0236	0.0239	0.996
4.5	MC	0.44	0.43	0.72	0.0228	0.0221	0.9962
4.5	NO	0.43	0.43	0.72	0.0228	0.0223	0.9958
8.5	AC	0.49	0.48	0.75	0.0245	0.026	0.996
8.5	BC	0.49	0.48	0.76	0.0245	0.0251	0.9956
8.5	CC	0.475	0.46	0.73	0.0237	0.0247	0.9961
8.5	CN	0.495	0.48	0.76	0.0245	0.0243	0.9958
8.5	GF	0.69	0.68	0.86	0.0294	0.0355	0.9959
8.5	HE	0.575	0.555	0.79	0.027	0.0282	0.9965
8.5	IN	0.485	0.47	0.75	0.0247	0.0247	0.9958
8.5	IP	0.55	0.54	0.83	0.0275	0.0295	0.9957
8.5	MC	0.51	0.485	0.77	0.0264	0.0254	0.9956
8.5	NO	0.49	0.48	0.74	0.0245	0.0235	0.9955

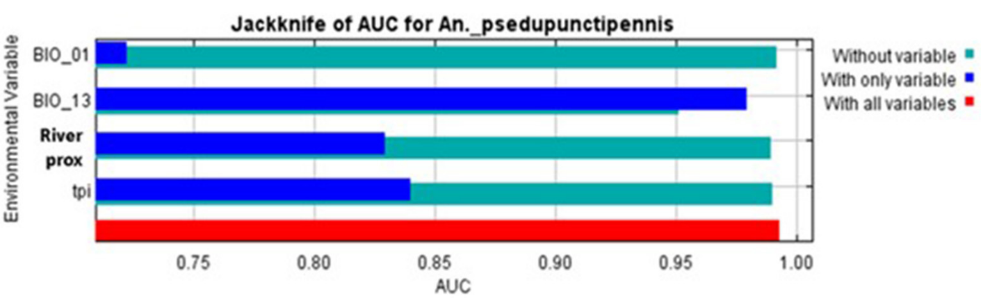

FIGURE 3 | *Jackknife* test model with variables BIO1, Bio13, river proximity, and topographic position index (TPI).

TABLE 2 | Regression logistic results using variables BIO 1, BiO 13, TPI, and river proximity.

Variable	ß coefficient	Standard error	*p*-value
BIO1	0.001898	0.000344	<0.01
BIO13	0.00001278	0.00004038	0.752
TPI	−0.0003896	0.00005867	<0.01
River proximity	−0.000000084298	0.000000007712	<0.01

DISCUSSION

This study assembled a local data set summarizing occurrences of *An.* (*Ano.*) *pseudopunctipennis* and provided detailed maps of its potential geographic distribution under current and future climatic conditions. The latter objective is important in anticipating any possible future distributional changes of *An.* (*Ano.*) *pseudopunctipennis* and the potential risk to human health posed by the reintroduction and transmission of malaria in northern Chile.

Under both climatic change scenarios, it was probable that conditions would permit an expansion of the geographic range of *Anopheles* species in several world regions (38). According to the *An.* (*Ano.*) *pseudopunctipennis* distribution model in Chile, its presence probability would increase in its geographic extent under both scenarios (by 38% in RCP 4.5 and by 101% in RCP 8.5). These results fitted with the expected projection for the geographic range of *An.* (*Ano.*) *pseudopunctipennis* given insect adaptation to climate change effects (39–41).

In the three scenarios analyzed (the current scenario, RCP 4.5, and RCP 8.5), we observed an area of medium

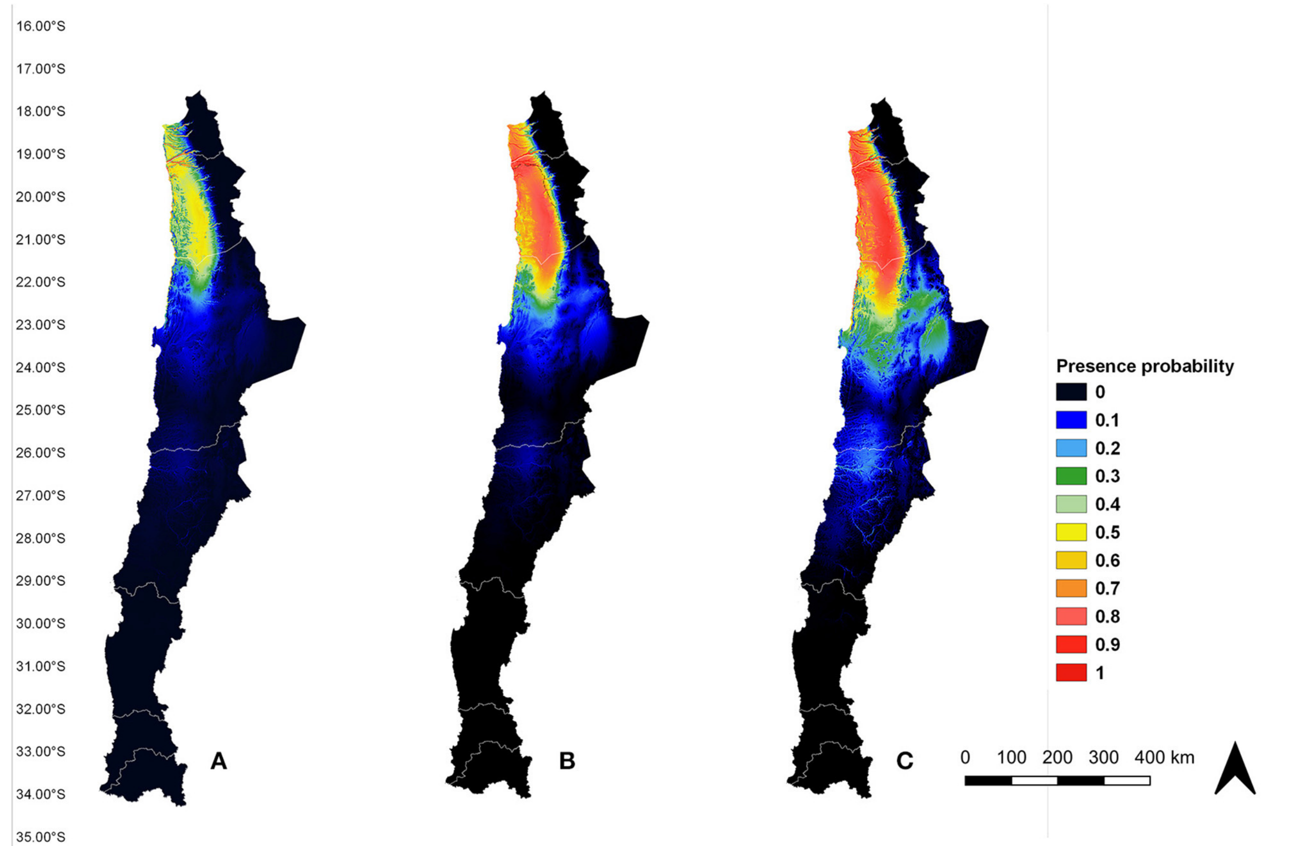

FIGURE 4 | *An. (Ano.) pseudopunctipennis* potential distribution model in Chile under current **(A)**, RCP 4.5 **(B)**, and RCP 8.5 **(C)** scenarios. Model GF.

presence probability for the current model (**Figure 4A**) and of high presence probability in the RCP 4.5 and RCP 8.5 models (**Figures 4B,C**), extending from the north of the Arica y Parinacota region (18°21′S latitude) to the north of the Antofagasta region (21°53′S latitude), along the Andes mountains. This area shares similar topology, bioclimatic, and vegetational characteristics, typical of the desert (42).

"TPI" and "river proximity" were the topographic layers most relevant in the model. Both variables were negatively related to the model, meaning there was a higher *An.* (*Ano.*) *pseudopunctipennis* presence probability in areas capable of retaining the water from river flooding. This reflects the preference of this species to lay eggs in fresh water pools formed near riverbanks (4).

The projections for the north of Chile should be interpreted with caution due to inconsistent record keeping regarding precipitation during the last century. In addition, northern Chile precipitation records are lower than what is typical in tropical areas, probably causing errors in statistical models (12). Nevertheless, precipitation level is a relevant variable to predict the presence of this species because it is important for the aquatic development of immature mosquito stages, especially in arid regions like northern Chile. Furthermore, higher precipitation is associated with an increased reproductive rate and distribution expansion in insects (39–41). The *An.* (*Ano.*) *pseudopunctipennis* population in Chile is already known to increase after summer rainfall due to a plateau-style winter ("Invierno altiplánico"). It is not possible to predict how this climate phenomenon will behave under climate change scenarios because it depends on the "South Pacific Anticyclone" (42). However, an intensification of this type of phenomenon has been observed in association with the effects of climate change in recent years (43). Thus, there is a possibility that summer rains will increase in the RCP 4.5 and 8.5 scenarios, affecting positively the presence probability of *An.* (*Ano.*) *pseudopunctipennis*. Nevertheless, precipitation layers are controversial for this vector distribution model because intense rains are also responsible for the destruction of its breeding sites. Although "precipitation in the wettest month" (BIO13) was the most relevant variable according to the *Jackknife* test, logistic regression showed that "BIO13" was not significant for the model ($p = 0.752$), perhaps because of its controversial contribution to *An.* (*Ano.*) *pseudopunctipennis* presence.

"Annual mean temperature" (BIO1) increases also had an impact in the distribution of this vector. Higher temperatures decrease the duration of the development cycle and increase fecundity, survival rates, population density, and dispersion capacity in insects (39–41). Therefore, increases in projected temperatures under both climate change scenarios would be expected to enhance the geographic extent of the presence probability area.

"Human footprint" was not a predictive variable for the model because this vector is distributed in rural areas, removed from human population centers in northern Chile (6), and feeding primarily on local animal hosts (44, 45).

Under both projected scenarios, there was a low (**Figure 4B**) to medium (**Figure 4C**) presence probability of this species in the "Salar de Atacama." As in the case of the Loa river, the salinity of the water in the "Salar de Atacama" would not permit the development of *An. (Ano.) pseudopunctipennis* immature stages (24).

Under all three scenarios, there was a low presence probability of this vector around the border of the Antofagasta and Atacama regions (between 25°23′S and 26°40′S latitudes). Although topographic and bioclimatic characteristics are likely similar to the areas where *An. (Ano.) pseudopunctipennis* is present, it would be unusual to find this species in this region because it is completely isolated from the areas with known presence of this vector.

Nevertheless, several *An. (Ano.) pseudopunctipennis* specimens have been collected in Arica city and the nearby Matilla village (Tarapacá region) in the last 3 years [unpublished data, Laboratorio de Referencia de Entomología ISP; (10)]. Perhaps this species is re-infesting areas where it was historically found, or perhaps it is adapting to new climatic conditions, like temperature increment and intense precipitations events. This situation poses a risk of re-introducing autochthonous malaria transmission to Chile, especially because northern Chile is a transit and immigration zone for people coming from malaria-endemic countries, like Perú and Bolivia (11).

In conclusion, these analyses provide guidance regarding areas that are potentially vulnerable to the reintroduction of autochthonous malaria transmission in Chile and will help to optimize the response to any eventual outbreaks of the disease. Species distribution models are very relevant to generate human, animal, and environmental health knowledge contributing to the "One Health" concept.

DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. This data can be found at: https://www.portaltransparencia.cl/PortalPdT/ingreso-sai-v2?idOrgTa=AO005.

AUTHOR CONTRIBUTIONS

LV designed the study, made the data analysis, and wrote the manuscript. SA helped with the data analyses and revised the manuscript. CR made the field work and revised the manuscript. CRG collaborated in the study design, made the field work, and revised the manuscript. All authors contributed to the article and approved the submitted version.

FUNDING

We are thankful to the Dirección de Investigación y Postgrado of the Universidad Metropolitana de Ciencias de la Educación) and One Health Latin America + Ibero and The Caribbean (www.ohlaic.org) Network for financial support.

ACKNOWLEDGMENTS

The data utilized in this study were recopilated from the Laboratorio de Referencia de Entomología del Instituto de Salud Pública de Chile and Oficinas Regionales de Zoonosis y Vectores de las Secretarías Regionales Ministeriales de Salud records. We are grateful to these institutions for sharing the information with us. We thank the assistance of Daniela Figueroa (Universidad Adolfo Ibáñez, Departamento de Ciencias, Facultad de Artes Liberales, Santiago, Chile), Antonio Rivera (Instituto de Entomología, Universidad Metropolitana de Ciencias de la Educación, Facultad de Ciencias Básicas, Santiago, Chile), and Patricia Estrada (Instituto de Entomología, Universidad Metropolitana de Ciencias de la Educación, Facultad de Ciencias Básicas, Santiago, Chile) in the study development and of Audrey Lenhart [Center for Global Health, Division of Parasitic Diseases and Malaria, Entomology Branch, U.S Centers for Disease Control and Prevention (CDC), U.S.A] for the English translation revision.

REFERENCES

1. Forattini OP. Gênero *Anopheles*. subgênero *Anopheles*. In: Forattini OP, editor. *Culicidologia Médica*. Saõ Paulõ: Saõ Paulõ University (2002). p. 249–78.
2. Rueda LM, Peyton EL, Manguin S. *Anopheles (Anopheles) pseudopunctipennis* theobald (diptera: culicidae): neotype designation and description. *J Med Entomol.* (2004) 41:12–22. doi: 10.1603/0022-2585-41.1.12
3. Manguin S, Roberts DR, Peyton EL, Fernandez-Salas I, Barreto M, Loayza RF, et al. Biochemical systematics and population genetic structure of *Anopheles pseudopunctipennis*, vector of malaria in Central and South America. *Am J Trop Med Hyg.* (1995) 53:362–77. doi: 10.4269/ajtmh.1995.53.362
4. Manguin S, Roberts DR, Peyton EL, Rejmankova E, Pecor J. Characterization of *Anopheles pseudopunctipennis* larval habitats. *Am J Trop Med Hyg.* (1996) 12:619–26.
5. Foster PG, de Oliveira TMP, Bergo ES, Conn JE, Sant'Ana DC, Nagaki SS, et al. Phylogeny of Anophelinae using mitochondrial protein coding genes. *R Soc Open Sci.* (2017) 4:170758. doi: 10.1098/rsos.170758
6. González CR, Reyes C, Jercic MI, Rada V, Saldarriaga M, Pavletic C, et al. *Manual de Culícidos (Diptera: Culicidae) de la zona Norte y Centro de Chile, incluyendo Isla de Pascua*. 2nd edn. Santiago: Instituto de Salud Pública de Chile, Ministerio de Salud de Chile (2016).
7. Schenone FH, Olea NA, Rojas SA, García DN. Malaria en Chile: 1913–2001. *Rev Méd Chile.* (2002) 130:1170–6. doi: 10.4067/s0034-98872002001000013
8. Pérez CC, Baudrand BR, Labarca LJ, Perret PC, Andresen HM, Guzmán DA. Malaria: revisión retrospectiva de 12 casos no autóctonos en Chile. *Rev Méd Chile.* (2006) 134:421–5. doi: 10.4067/S0034-98872006000400003
9. Instituto de Salud Pública (ISP). *Vigilancia de Malaria. Chile, 2011–2018. Boletín Vigilancia de Laboratorio ISP*. (2019). Available online at: http://www.ispch.cl/sites/default/files/Boletin%20Malaria-final_2019.pdf (accessed April 5, 2019).

10. Cancino B. *Study of Presence of Flavivirus and Dirofilaria by Molecular Tools in Mosquitoes (Diptera: Culicidae) in a Desertic Zone of Chile*. Talca: Universidad Católica del Maule (2018).
11. Urzúa A, Vega M, Jara A, Trujillo S, Muñoz R, Caqueo-Urízar A. Calidad de vida percibida en inmigrantes sudamericanos en el norte de Chile. *Ter Psicol.* (2015) 33:139–56. doi: 10.4067/S0718-48082015000200008
12. Sarricolea P, Meseguer Ruiz O, Romero Aravena H. Tendencias de la precipitación en el norte grande de Chile y su relación con las proyecciones de cambio climático. *Diálogo Andino.* (2017) 54:41–50. doi: 10.4067/S0719-26812017000300041
13. Ministerio de Medio Ambiente. *Plan de Acción Nacional de Cambio Climático 2017-2022*. Santiago: Gobierno de Chile (2017). doi: 10.3738/1982-227872
14. Garreaud RD. Climático producto del incremento de efecto invernadero de origen antropogénico. *Rev Tierra Adentro.* (2011) 93:13–19. Avaible online at: https://biblioteca.inia.cl/handle/123456789/5214
15. Schulz N, Boisier JP, Aceituno P. Climate change along the arid coast of northern Chile. *Int J Climatol.* (2011) 32:1803–1814. doi: 10.1002/joc.2395
16. Alimi TO, Fuller DO, Qualls WA, Herrera SV, Arevalo-Herrera M, Quinones ML, et al. Predicting potential ranges of primary malaria vectors and malaria in northern South America based on projected changes in climate, land cover and human population. *Parasit Vectors.* (2015) 8:1–16. doi: 10.1186/s13071-015-1033-9
17. Padilla O, Rosas P, Moreno W, Toulkeridis T. Modeling of the ecological niches of the *Anopheles* spp in Ecuador by the use of geo-informatic tools. *Spat Spatio-Temporal Epidemiol.* (2017) 21:1–11. doi: 10.1016/j.sste.2016.12.001
18. Pakdad K, Hanafi-Bojd AA, Vatandoost H, Sedaghat MM, Raeisi A, Moghaddam AS, et al. Predicting the potential distribution of main malaria vectors *Anopheles stephensi*, An. *culicifacies s.l.* and *An. fluviatilis s.l.* In Iran based on maximum entropy model. *Acta Tropica.* (2017) 169:93–9. doi: 10.1016/j.actatropica.2017.02.004
19. Hijmans RJ, Elith J. *Species Distribution Modeling With R Introduction*. (2017). Available online at: https://cran.r-project.org/web/packages/dismo/vignettes/sdm.pdf (accessed December 10, 2018).
20. Phillips SJ, Dudík M, Schapire RE. *Maxent Software for Modeling Species Niches and Distributions*. (2018). Available online at: http://biodiversityinformatics.amnh.org/open_source/maxent (accessed March 13, 2018).
21. Hijmans RJ, Cameron SE, Parra JL, Jones PG, Jarvis A. Very high resolution interpolated climate surfaces for global land areas. *Int J Climatol.* (2005) 25:1965–78. doi: 10.1002/joc.1276
22. Escobar LE, Peterson AT, Papeş M, Favi M, Yung V, Restif O, et al. Ecological approaches in veterinary epidemiology: mapping the risk of bat-borne rabies using vegetation indices and night-time light satellite imagery. *Vet Res.* (2015) 46:1–10. doi: 10.1186/s13567-015-0235-7
23. Astorga F, Escobar LE, Poo-Muñoz D, Escobar-Dodero J, Rojas-Hucks S, Alvarado-Rybak M, et al. Distributional ecology of andes hantavirus: a macroecological approach. *Int J Health Geogr.* (2018) 17:1–12. doi: 10.1186/s12942-018-0142-z
24. Espinoza S, Keegan T, Fanfani L, Alonso H, Droguett F. Resultados preliminares de un estudio de sedimentos de fondo en el río Loa, 2a region, Chile. [dissertation]. *Congreso Internacional Ciencias de la Tierra Chile*. Santiago: Ponencias Ciencias Físicas y Humanas (2000).
25. Wildlife Conservation Society - WCS, and Center for International Earth Science Information Network - CIESIN - Columbia University. *Data from: Last of the Wild Project, (LWP-2): Global Human Footprint Dataset (Geographic)*. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC) (2005). doi: 10.7927/H4M61H5F
26. Figueroa DP, Scott S, González CR, Bizama G, Flores,- R, Bustamante R, et al. Estimating the climate change consequences on the potential distribution of *Culex pipiens* L. 1758, to assess the risk of West Nile virus establishment in Chile. *Gayana*. (2020) 84:46–53. doi: 10.4067/S0717-65382020000100046
27. Endries M. *Aquatic Species Mapping in North Carolina Using Maxent*. Asheville North Carolina. (2001). Available online at: https://www.fws.gov/asheville/htmls/maxent/Aquatic Species Mapping in North Carolina using Maxent V2.pdf (accessed August 09, 2020).
28. Warren DL, Seifert S. Ecological niche modeling in Maxent: the importance of model complexity and the performance of model selection criteria. *ESA*. (2011) 21:335–42. doi: 10.1890/10-1171.1
29. Yang XQ, Kushwaha SPS, Saran S, Xu J, Roy PS. Maxent modeling for predicting the potential distribution of medicinal plant, *Justicia adhatoda* L. in Lesser Himalayan foothills. *Ecol Eng.* (2013) 51:83–7. doi: 10.1016/j.ecoleng.2012.12.004
30. Erfanfar D, Sarafrazi A, Ghanbalani GN, Ostovan H. Claims of potential expansion and future climatic scenarios for Orius species (Hemiptera: Anthocoridae) throughout Iran. *Eur J Zool Res.* (2014) 3:43–55.
31. Kienast F, Bolliger J, Zimmermann NE. Species Distribution Modeling (SDM) with GLM, GAM and CART Dependent vs. independent variables: a conceptual ecological view. In: *Advanced Landscape Ecology*. Zürich: Department of Environmental Sciences, ETH Zürich (2012).
32. Burnham KP, Anderson RP. Multimodel inference understanding AIC and BIC in model selection. *Sociol Methods Res.* (2004) 33:261–304. doi: 10.1177/0049124104268644
33. Phillips SJ, Avenue P, Park F. A maximum entropy approach to species distribution modeling. In: *Twenty-First International Conference on Machine Learning*. New York, NY, (2004). p. 655–62.
34. Muscarella R, Galante PJ, Soley-Guardia M, Boria RA, Kass JM, Uriarte M, et al. ENMeval: An R package for conducting spatially independent evaluations and estimating optimal model complexity for <scp>Maxent</scp> ecological niche models. *Methods Ecol Evol.* (2014) 5:1198–205. doi: 10.1111/2041-210X.12261
35. Muscarella R, Galante PJ, Soley-Guardia M, Boria RA, Kass JM, Uriarte M, et al. *ENMeval: Automated Runs and Evaluations of Ecological Niche Models. R package.* (2018). Available online at: https://cran.r-project.org/web/packages/ENMeval/index.html (accessed August 11, 2020).
36. R Core Team. R: *A Language and Environment for Statistical Computing*. Vienna: R Foundation for Statistical Computing. (2014). Available online at: http://www.R-project.org/
37. Liu C, Berry PM, Dawson TP, Pearson RG. Selecting thresholds of occurrence in the prediction of species distributions. *Ecography.* (2005) 28:385–93. doi: 10.1111/j.0906-7590.2005.03957.x
38. Tonnang HE, Kangalawe RY, Yanda PZ. Predicting and mapping malaria under climate change scenarios: the potential redistribution of malaria vectors in Africa. *Malar J.* (2010) 9:111. doi: 10.1186/1475-2875-9-111
39. Bale JS, Masters GJ, Hodkinson ID, Awmack C, Bezemer TM, Brown VK, et al. Herbivory in global climate change research: direct effects of rising temperature on insect herbivores. *Glob Change Biol.* (2002) 8:1–16. doi: 10.1046/j.1365-2486.2002.00451.x
40. Musolin DL. Insects in a warmer world: Ecological, physiological and life-history responses of true bugs (Heteroptera) to climate change. *Glob Change Biol.* (2007) 13:1565–85. doi: 10.1111/j.1365-2486.2007.01395.x
41. Ogden NH, Lindsay LR. Effects of climate and climate change on vectors and vector-borne diseases: ticks are different. *Trends Parasitol.* (2016) 32:646–56. doi: 10.1016/j.pt.2016.04.015
42. Luebert F, Pliscoff P. *Sinopsis Bioclimática y Vegetacional de Chile*. 2nd edn. Santiago: Editorial Universitaria S.A. (2017).
43. Villarroel JC. Evidencias y proyecciones de cambio climático en Chile. In: *Simposium: Anopheles pseudopunctipennis y el Riesgo de Aparición de Malaria, en el Norte de Chile, Bajo Escenarios de Cambio Climático*. Santiago: Instituto de Salud Pública de Chile (2018).
44. Lardeux F, Loayza P, Bouchité B, Chavez T. Host choice and human blood index of *Anopheles pseudopunctipennis* in a village of the Andean valleys of Bolivia. *Malar J.* (2007) 6:1–14. doi: 10.1186/1475-2875-6-8
45. Sinka ME, Rubio-Palis Y, Manguin S, Patil AP, Temperley WH, Gething PW, et al. The dominant *Anopheles* vectors of human malaria in the Americas: occurrence data, distribution maps and bionomic precis. *Parasit Vectors.* (2010) 3:72. doi: 10.1186/1756-3305-3-72

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Public Health

PERSPECTIVE
published: 04 June 2021
doi: 10.3389/fpubh.2021.644748

Public Policies and One Health in Brazil: The Challenge of the Disarticulation

Isis de Freitas Espeschit[1]*, *Clara Marques Santana*[2] and *Maria Aparecida Scatamburlo Moreira*[1]

[1] Laboratory of Bacterial Diseases, Preventive Veterinary Medicine and Public Health Sector, Veterinary Department, Universidade Federal de Viçosa, Viçosa, Brazil, [2] Medical School, Universidade Federal de Juiz de Fora, Valadares, Brazil

Working the One health strategy in developing countries is a challenge, due to structural weaknesses or deprivation of financial, human, and material resources. Brazil has policies and programs that would allow continuous and systematic monitoring of human, animal, and environmental health, recommending strategies for control and prevention. For animals, there are components of the Epidemiological Surveillance of zoonosis and Animal Health Programs. To guarantee food safety, there are Health Surveillance services and support of the Agropecuary Defense in the inspection of these products, productive environments, and their inputs. Environmental Surveillance Services monitor water and air quality, which may influence health. For human health, these and other services related to Health Surveillance, such as Worker Health and Epidemiological Surveillance, which has a training program responsible for forming professionals groups to respond effectively to emergencies in public health are available. Therefore, Brazil has instruments that may allow integrated planning and intervention based on the One Health initiative. However, the consolidation of this faces several challenges, such as insufficient resources, professional alienation, and lack of the recognition of the importance of animal and environmental health for the maintenance of human and planetary well-being. This culminates in disarticulation, lack of communication, and integration between organizations. Thus, efforts to share attributions and responsibilities must be consolidated, overcoming the verticality of the actions, promoting efficiency and effectiveness. Finally, this perspective aims to describe the government instruments that constitute potential national efforts and the challenges for the consolidation of the One Health initiative in Brazil.

Keywords: Health Surveillance, agricultural defense, animal health, animal-human bond, zoonosis

OPEN ACCESS

Edited by:
Christina Pettan-Brewer, University of Washington, United States

Reviewed by:
Maxine Anne Whittaker, James Cook University, Australia
Susan Christina Welburn, University of Edinburgh, United Kingdom

****Correspondence:***
Isis de Freitas Espeschit
isisdefreitasespeschit@gmail.com

Specialty section:
This article was submitted to Planetary Health, a section of the journal Frontiers in Public Health

Received: *21 December 2020*
Accepted: *27 April 2021*
Published: *04 June 2021*

Citation:
Espeschit IdF, Santana CM and Moreira MAS (2021) Public Policies and One Health in Brazil: The Challenge of the Disarticulation. Front. Public Health 9:644748. doi: 10.3389/fpubh.2021.644748

INTRODUCTION

One Health is an integrative and cooperative health initiative, with a transdisciplinary approach to health promotion and surveillance at the local, regional, national or global level, aiming to achieve optimal health conditions, given the recognition of the interconnection and interdependence between human, animals, and the environment (1, 2).

Historically, the perspective that environmental health affects humans has existed since the classical era. Hippocrates stated that biological and environmental conditions affect human health (3). Afterward, Aristotle and Galen sought to elucidate similarities between human and animal vital systems, allowing the creation of Comparative Medicine (4, 5).

In the 19th century, pathologist Robert Virchow coined the term "zoonosis," to name diseases transmitted from animals to humans, based on his observations with helminths, believing that there is no separation between animal and human health (5, 6).

Despite the recognition of this relationship, it was only 1970s that the epidemiologist Calvin Schwabe introduced the "One Medicine" theory, to name, in a holistic way, the connection between animals and humans in nutrition, habitat, and health, stating that both human and veterinary medicine have the same scope in physiology, anatomy, and pathology (7, 8).

The United Nations (UN), World Health Organization (WHO), Food and Agriculture Organization of the United Nations (FAO), and the World Organization for Animal Health (OIE) have recently established a cooperation to promote the perspective of One Health, encouraging the implementation of government policies and programs guided by it (9–11).

To this end, the Global Health Security Agenda (GHSA) was signed in 2014 with more than 64 nations and international non-governmental organizations supporting the collaborative approach. This will accelerate the consolidation and compliance of the requirements from the OIE Terrestrial and Aquatic Animal Health Codes, the WHO International Health Regulations (IHR), and other global health regulations for planetary health (8, 12, 13).

Despite the increase in rhetoric and support for the One Health model, it is difficult to find authentic examples of multidisciplinary or multi-sectoral efforts that transcend traditional public, animal, and environmental health "silos" (13, 14).

The ability to face threats to public and animal health effectively and efficiently requires effort and proper planning. A prerequisite for this is the training and capacitation of the public and private health sectors. However, this, within the One Health strategy, remains a challenge, especially for developing countries. This stems from competing priorities, insufficient and fragmented funding, with a lack of integration and communication between sectors (14, 15).

Some positive international experiences in this path have been reported, such as the One Health Workforce (OHW) project by the United States Agency for International Development (USAID). This aims to build partnerships with institutions and leaders in Africa and Southeast Asia to assist in the identification of technical, collaborative, and organizational characteristics, important for the development of the workforce in alignment with the goals established in the GHSA and by the Joint External Evaluation– International Health Regulations (JEE – IHR) (16, 17).

In Latin America, the incorporation of the One Health strategy into government plans is timid and the integration of animal, environmental and human programs and sectors is insignificant (9–11).

In Brazil, the One Health concept itself requires recognition by health professionals and is not acknowledged by important entities such as the Federal Council of Medicine. As an effect, the power of interventions and control strategies over the environmental causes of diseases is limited, and these activities are often restricted to veterinary professionals. On the other hand, public policies for Health Surveillance (HS) have allowed the gradual insertion of One Health supportive efforts in health practices, however with little integration between their organizations (9–11, 17, 18).

An adequate surveillance system, with a strong laboratory network, is the key component of any disease prevention and control strategy. To develop an effective One Health implementation plan, it is necessary to reexamine how the existing systems are structured, resourced, and managed. These analyzes would contribute to the development and sustainability of the synergy between human, animal, and environmental health initiatives (12–14, 19).

Thus, this perspective article aims to present the potential, successes and challenges of government health strategies, programs and policies in Brazil, from One Health point of view. The present discussion is based on the analysis of the official documents, legislation and health informational systems.

THE POTENTIAL GOVERNMENT INSTRUMENTS FOR THE CONSOLIDATION OF ONE HEALTH IN BRAZIL

One of the most important aspects of pathogen control at the human, animal, and environmental interface is the development of appropriate scientific-based Surveillance and Risk Management policies that respect transboundary regulations (12, 14, 19).

In Brazil, there is a complex system for monitoring human, animal, and environmental health conditions, based on the Health Surveillance System (HSS) and in the use of epidemiology as a planning tool. This system is supported by organizations such as the Ministério da Agricultura Pecuária e Abastecimento- MAPA (Ministry of Agriculture, Livestock and Supply) and the Sistema Único de Saúde- SUS (Unified Health System) and its respective policies, programs, regulations, and health information systems as summarized in **Tables 1**, **2** and described in detail in the following text (46–49).

Brazil's health system emerged due to an organizational restructuring and popular social movements. With the implementation of this universal and integral system, normative actions created for stimulation of the HSS, brought with it the redefinition of health practices, allowing their greater integration with epidemiology. This surveillance system is based on four main pillars, focused mainly on conditions that affect human health, namely: Epidemiological, Sanitary, Environmental and Occupational Health Surveillance Systems (12–15, 50).

The National Environmental Health Surveillance System performs continuous and systematic monitoring of environmental conditions that may interfere with human

TABLE 1 | Organizational components of Health Surveillance System (HSS) programs and policies regarding the human, animal, and environmental health.

Acronym	Program	Regulations
HUMAN AND ANIMAL HEALTH SURVEILLANCE		
ESS	Epidemiological Surveillance System Zoonosis Epidemiological Surveillance System	Ordinance No. 2,254, OF AUGUST 5, 2010 Institutes Epidemiological Surveillance in Hospital Settings defines the competencies for the Union, the States, the Federal District, the Municipalities, the criteria for the qualification of the national reference hospital units and defines the scope of the activities to be developed by the Hospital Centers of Epidemiology (20). LAW No. 6,259, OF OCTOBER 30, 1975. Provides for the organization of Epidemiological Surveillance actions, the National Immunization Program establishes rules regarding the compulsory notification of diseases and provides other measures (21). NATIONAL COUNCIL OF HEALTH SECRETARIES-TECHNICAL NOTIFICATION, 02 / 2014- 2 definition of health actions and services aimed at surveillance, prevention, and control of zoonosis and accidents caused by venomous and poisonous animals, of relevance to public health (22).
EpiSUS	Training program in Applied Epidemiology to the Services of the Unified Health System	MINISTRY OF HEALTH - Ordinance No. 1,430, OF JUNE 11, 2018- Amends Consolidation Ordinance No. 5, of September 28, 2017, to institute the Training Program in Epidemiology Applied to the Services of the Unified Health System - EpiSUS Program (23).
OHS	Occupational Health Surveillance	MINISTRY OF HEALTH - Ordinance No. 1,823, OF AUGUST 23, 2012-Institutes the National Policy for Workers' Health (24). MINISTRY OF HEALTH. Ordinance No. 1339. 1999 November 18. To institute the List of Work-related Diseases, to be adopted as a reference for injuries originated in the work process in the Unified Health System, for clinical and epidemiological use, contained in Annex I of this Ordinance (25).
ENVIRONMENTAL HEALTH SURVEILLANCE		
VIGIÁGUA	Water Quality Monitoring Program	Ordinance No. 2,914 of December 12, 2011, provides for the control and surveillance procedures of the quality of water for human consumption and its drinking water standard.
VIGIPEQ	Health Surveillance of Populations Exposed to Chemical Contaminants	Ministry of Health of Brazil. National health surveillance program for populations exposed to contaminated soil. 2007. Brasília (26).
VIGISOLO	Health Surveillance of Populations Exposed to Contaminated Soil	Normative Instruction MS No. I of March 7, 2005 - Regulates Ordinance No. 1,172 / 2004 / GM, concerning the competencies of the Union, states, municipalities, and the Federal District in the area of environmental health surveillance (27).
VIGIDESASTRES	Environmental Health Surveillance related to Natural Disasters	NATIONAL HEALTH FOUNDATION. Guide to environmental health surveillance / National Health Foundation. 2002. Brasília (28).
VIGIAR	Air Quality Monitoring Program	

These components are part and subject to the national Unified Health System (SUS- Sistema Único de Saúde).

and animal health such as water, soil, air, biological factors and vectors, environmental disasters, and accidents with contaminants. The operational instruments to make this viable are VIGIÁGUA (evaluates the quality of water for human consumption), VIGIPEQ (acts on environmental contaminating chemicals), VIGISOLO (acts on the quality of soil and cultivation activities), VIGIAR (evaluates air quality), and VIGIDESASTRES (surveillance and management of environmental disasters) (26–28, 46–48).

The Epidemiological (ES) component of the Surveillance System is responsible for systematic monitoring of adverse health events, and control measures proposition, consolidated by the National ES System and its sub-areas, allowing significant advances in the capacity to respond to health problems. ES monitors communicable and non-communicable diseases and other health problems, such as accidents, violence, and a strategic area, that performs Zoonosis Surveillance, recognizing the importance of the animal-human bond. The latter is responsible for monitoring the progress of animal diseases and accidents with venomous animals. The recognition of the importance of zoonotic diseases by the health system is extremely relevant; both for management and for the health care itself, since, on average 60–80% of human diseases are of animal origin (20–25, 49, 51–53).

In the context of ES, Brazil also has a Training program in Applied Epidemiology to the Services of the Unified Health

TABLE 2 | Organizational components of Health Surveillance System (HSS) programs and policies regarding the human, animal, and environmental health in Brazil.

Acronym	Program	Regulations
MAPA- MINISTÉRIO DA AGRICULTURA, PECUÁRIA E ABASTECIMENTO (MINISTRY OF AGRICULTURE, LIVESTOCK AND SUPPLY)		
VIGIAGRO	Agropecuary Surveillance/defense	Law 8,171, of January 17, 1991 - Provides for agricultural policy (29). Decree n° 30.691, of March 29, 1952 -Institutes the Regulation of Industrial and Sanitary Inspection of Products of Animal Origin and obliges MAPA to inspect animals and derived products in the sea and river ports and border posts. Institutes the Inspection Regulation Industrial and Sanitary Products of Animal Origin and obliges MAPA to inspect animals and derived products in sea and river ports and border posts (30). Law No. 6,198, of December 26, 1974 - Forces MAPA to inspect products for animal feed in ports and border posts. Forces MAPA to inspect products for animal feed in ports and border posts (31). Law No. 7,802, of July 11, 1989 - Forces the Federal Government to inspect the import of pesticides (32). Law No. 7,678, of November 8, 1988 - Provides for the production, circulation, and commercialization of wine and grape and wine derivatives, and makes other provisions (33). Law No. 8,918, of July 14, 1994 - Provides for the standardization, classification, registration, inspection, production, and inspection of beverages, authorizes the creation of the Intersectorial Beverage Commission, and makes other provisions (34). Decree No. 24,114 of April 12, 1934. - Organizes the Unified System of Attention to Agricultural Health and makes other provisions (35). Normative Instruction No. 51, of November 7, 2011 (36). Normative Instruction No. 91, of September 18, 2020 - Provides for the Use of the LPCO Module in Import Operations for Products of Agricultural Interest (37). Annex IN 51/2011 - NCM list of products that will meet the regulatory criteria and procedures for inspection, inspection, quality control, and risk analysis systems, established by the Ministry of Agriculture, Livestock and Supply (MAPA) (36).
AHP	Animal Health Programs, namely: National Equine Health Program National Poultry Health Program	MAPA - Normative Instruction No. 6, of January 16, 2018, institutes the National Equine Health Program (38). MINISTERIAL ORDINANCE No. 193, SEPTEMBER 19, 1994- Establishes the National Poultry Health Program within the scope of the DSA and creates the Consultative Committee of the Poultry Health Program (39).
	National Program for the Control and Eradication of Brucellosis and Tuberculosis	MAPA - Normative Instruction 02/2001 Normative Instruction SDA n° 10/2017, to reduce the negative impacts of Brucellosis and Tuberculosis on human and animal health (40).
	National Goat and Sheep Health Program	MAPA - Normative Instruction No. 87, of December 10, 2004. Institutes the National Program for the Health of Goats and Sheep (41).
	National Herbivore Rabies Control Program	MAPA - Normative Instruction No. 5 01/03/200, Approves the Technical Norms for the control of rabies of domestic herbivores (42).
	National Apiculture Health Program	MAPA - Normative Instruction No. 16, of May 8, 2008, institutes the National Program for Beekeeping Health (PNSAp) (43).
	National Program for the Eradication and Prevention of Foot-and-Mouth Disease,	MAPA - Normative Instruction No. 44 of 10/02/2007 Approves the general guidelines for the Eradication and Prevention of Foot-and-Mouth Disease, to be observed throughout the National Territory, with a view to the implementation of the National Program for the Eradication and Prevention of Foot-and-Mouth Disease (PNEFA), like the one established by the Unified Agricultural Health Care System (44).
ANVISA- AGÊNCIA NACIONAL DE VIGILÂNCIA SANITÁRIA-(NATIONAL AGENCY OF SANITARY SURVEILLANCE)		
	Sanitary Surveillance System	Law No. 9,782, of January 26, 1999, institutes the National Health Surveillance Agency, which is responsible for ensuring the safety and quality of goods, products, environments, inputs, and services that can convey risks to individual or collective health (45).

System- EpiSUS, part of the Department of Surveillance of Communicable Diseases of the Health Surveillance System. This program counts with multidisciplinary teams, aiming to enhance the ability to respond to public health emergencies and encourage the exchange of professionals and experiences at national and international levels, to improve the national technical capacity in field epidemiology, becoming an international reference in this field (23, 51, 53–57).

The Occupational Health Surveillance, part of HSS, monitors occupational risk factors and determinants of human health conditions that are related to the production and labor processes, as well as the ones related to the work environment (23, 54–57).

The Sanitary Surveillance System, coordinated by ANVISA, the national agency for Sanitary Surveillance, works in the regulation, control, and inspection of goods, products, and environments that are directly or indirectly related to health conditions, from production to consumption. It is recognized as a set of integrated institutional, administrative, programmatic, and social strategies, guided by public policies that aim the elimination, reduction, or prevention of individual and collective health risks, based on comprehensive services and actions that are essential to the health defense and promotion. This breadth of activities justifies the fact that these actions are developed as a democratic and participatory exercise and in an articulated way, to guarantee the quality of products, services, and environments, fundamental aspects for global health. Therefore, the Sanitary Surveillance is not restricted to purely technical actions, but its driving axes are actions aimed at the strengthening of the society and citizenship to promote health and preventing risks, damages or injuries (15, 45, 49, 54, 55, 58).

Also responsible for One Health, regarding animal health, food safety, trade and transit of products of animal and vegetable origin are the programs subjected to MAPA, the institution responsible for the National Agropecuary Defense (18, 57, 58).

The Agropecuary Defense relates to all stages of agricultural and livestock production, since the registration and inspection of agricultural inputs; production, industrialization, inspection and trade of products and by-products of animal and vegetable origin; besides acting in the import and export of inputs and products, as well as in the transit of these products and animals. In this way, it would not only promote and protect animal, human and environmental health but also help to increase economic incentives by promoting security and adding value to agricultural products (12, 29–36, 59–63).

Also subject to the National Agricultural Defense services, are the Animal Health Programs, namely: National Equine Health Program, National Poultry Health Program, National Program for the Control and Eradication of Brucellosis and Tuberculosis, National Goat and Sheep Health Program, National Herbivore Rabies Control Program, National Apiculture Health Program, National Program for the Eradication and Prevention of Foot-and-Mouth Disease, coordinated by MAPA (38–44, 61–64).

These programs aim to prevent, control, or eradicate diseases of public health importance or that may threaten international trade, ensuring animal health through health education activities; epidemiological studies; the inspection of breeding establishments, fiscalization of agricultural events and animal transit, notifying the occurrence of these diseases, in addition to guaranteeing the competitive value of the products in the international market (38–44, 61–64).

Furthermore, an operational instrument for Agropecuary Defense is VIGIAGRO, MAPA's instance that regulates the flow of animals, products, and agricultural inputs in frontiers, to ensure their safety and quality, preventing or minimizing potential risks to the One health (14, 18, 64–66).

In this construct, the programs and services presented have the potential for the insertion of the multidisciplinary and integrative approach of One Health, with intra and intersectoral collaboration Tis approach is appropriate to the current context of growing concerns about the consequences of the interactions between humans, animals, and the environment, in a productive framework based on capitalist ideals (58, 59, 67–69).

DISCUSSION

The importance of the policies and operationalization referred in this perspective article is acknowledged, but several challenges are found for the consolidation of its potential, the main ones being the disarticulation, the verticality of the actions, and the overlapping of attributions (1–5).

The central goals of the One Health model include altering the organization's work from a vertical and hierarchical approach to a horizontal and integrated one, in addition to moving from individual "silos" to a transdisciplinary functioning (1, 2, 14).

The difficulties in achieving these goals and in the integration between the spheres that work animal, human, and environmental health start in the professional training of those who work in these fields. Few individuals enter the workforce with crosscutting skills to thrive in transdisciplinary or multi-sectoral teams (14, 15).

The increase in the number and distribution of qualified personnel has proved to be one of the main limitations in most developing regions. This limitation, added to the financial, structural, and bureaucratic constraint faced by this sector, prevents it from satisfactorily exercising its potential, putting global health at risk (15).

The need and benefits of an integrated surveillance system to better understand the emergence and epidemiology of diseases have been demonstrated. This should count with a health care notification system and a comprehensive national database including environmental monitoring, human and animal health diagnostic systems, essential components of an integrated surveillance system, and for the implementation of One Health (12–15, 61).

Brazil has all these components, but they do not articulate or communicate. Even more, they sometimes overlap their attributions and compete for authority and hierarchy. The information produced by different organizations, rarely crosses that 'silo' that produced them, even though it could support health actions as a whole, producing and using information and communication in a shared way, to better instrumentalize the intervention (15).

For example, information on the incidence and prevalence of work-related illnesses could be used to modify production processes, minimizing the risks and potential damage. The occurrence of water and foodborne diseases could contribute to the improvement of the performance of Agropecuary Defense, among others. Just as, information about environmental health can be useful to guide all production processes, to help understanding the epidemiology and natural history of diseases, allowing the intervention in their origins. This would promote cheaper, more assertive, and definitive solutions to health problems and demands, making individuals, animals, and the environment healthier, more productive, and sustainable (12–15).

While some progress has been done, there is a need for continued investment and political commitment to address the persistent challenges in public health. As it can be seen in the **Tables 1**, **2**, the programs are not recent efforts and some of them are more than 20 years old. This is also a challenge since they are sealed in their 'silos', without undergoing major changes over the years and without communicating with other programs and institutions. Still in this sense, it is clear that changes in global initiatives and situations such as the pandemic due to the coronavirus have little or no influence on the construction of regulatory frameworks.

The One Health initiatives are of complex consolidation from both a political, technical, and sanitary perspective (12, 14, 15). The implementation of the strategies presented here, associated with the complex movement of political and administrative restructuring in Brazil represented progress in the direction of producing more effective interventions, however, it further aggravated the fragmentation and sectorization of health actions. This resulted in a surveillance based primarily on a routine centered on the notification and investigation of cases and the transmission of data to other levels for the consolidation of bases and information systems, frequently not reaching the final goal of triggering an intervention (15).

The lack of articulation and use of health information for planning interventions can be evidenced with a contemporary example. The COVID-19 pandemic and the recent worsening of it at the national level in early 2021 are the results of a lack of planning and intervention by governmental health spheres that have proved inefficient and non-resolute. Instead of applying the information, fees, numbers to equip their infrastructure and instruct their professionals, the highest governmental spheres have chosen to hide and fragment the health information consolidated by the Epidemiological Surveillance Systems and not apply it for planning and structuring measures to mitigate the health crisis (70–72).

The integration and articulation between health actions, organizations, and policies would promote greater effectiveness and efficiency of health interventions, promoting global health and expanding the response capacity. However, there are still restrict limits to the autonomy of federal entities in Brazil, perpetuating an excess of verticality in programs and decisions, which makes it difficult to move toward the integration of surveillance systems in the perspective of democratizing the health practices (15, 59, 73).

The action of these entities and services should be in the sense of sharing attributions and responsibilities, without leaving behind the technical specification of each of the areas. This would imply new roles, as well as new dynamics, relationships, and innovative practices at all levels, which denotes the complexity and challenge of its implementation (59, 73, 74).

Thus, it is proposed to work, from the One Health approach, in an articulated and integrated set of actions, which assume specific configurations according to the environmental, animal, and human health situation of each territory, transcending the institutionalized spaces of the health services system, the verticality, and hierarchy of agencies and programs. Thus, seeking a dialogue between "cause control," "risk control" and "damage control" through the redefinition of the object, the means of work, activities, and technical and social relations (12, 13, 15).

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

The authors contributed equally to all phases of the manuscript construction and revision.

FUNDING

The authors acknowledge the financial support from CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico), FAPEMIG (Fundação de Amparo a Pesquisa de Minas Gerais), and CAPES (Coordenação de Aperfeicoamento de Pessoal de Nível Superior). MM is supported by CNPq.

ACKNOWLEDGMENTS

The authors acknowledge the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior for the support in all scientific endeavors.

REFERENCES

1. McEwen SA, Collignon PJ. Antimicrobial resistance: a one health perspective. *Microbiol Spectr*. (2018) 6:521–47. doi: 10.1128/9781555819804.ch25
2. Zinsstag J, Crump L, Schelling E, Hattendorf J, Maidane YO, Ali KO, et al. Climate change and One Health. *FEMS Microbiol Lett*. (2018) 365:fny085. doi: 10.1093/femsle/fny085
3. Capua I, Cattoli G. One health (r) evolution: learning from the past to build a new future. *Viruses*. (2018) 10. doi: 10.3390/v10120725
4. Ryu S, Kim BI, Lim JS, Tan CS, Chun BC. One health perspectives on emerging public health threats. *J Prev Med Public Health*. (2017) 50:411–4. doi: 10.3961/jpmph.17.097
5. Conrad PA, Mazet JA, Clifford D, Scott C, Wilkes M. Evolution of a transdisciplinary "One Medicine–One Health" approach to global health

education at the University of California, Davis. *Prev Vet Med.* (2009) 92:268–74. doi: 10.1016/j.prevetmed.2009.09.002
6. Osburn B, Scott C, Gibbs P. One world—one medicine—one health: emerging veterinary challenges and opportunities. *Rev Sci Tech*. (2009) 28:481. doi: 10.20506/rst.28.2.1884
7. ATLAS, Ronald M. *One Health: Its origins and Future. One Health: The Human-Animal-Environment Interfaces in Emerging Infectious Diseases.* Berlin; Heidelberg: Springer (2012). p. 1–13.
8. Zinsstag J, Schelling E, Waltner-Toews D, Tanner M. (2011). From "one medicine" to "one health" and systemic approaches to health and well-being. *Prev Vet Med*. (2011) 101:148–56. doi: 10.1016/j.prevetmed.2010.07.003
9. Centers for Disease Control and Prevention. *One Health Basics*. Available online at: https://www.cdc.gov/onehealth/basics/index.html (accessed October 20, 2020).
10. Organização Mundial da Saúde. *Organização das Nações Unidas para Alimentação e Agricultura, Organização Mundial da Saúde Animal*. A Tripartite Concept Note. Geneva (2010) Available online at: https://www.who.int/influenza/resources/documents/tripartite_concept_note_hanoi/en/ (accessed October 20, 2020).
11. Evans BR, Leighton FA. A history of one health. *Rev Sci Tech*. (2014) 33:413–20. doi: 10.20506/rst.33.2.2298
12. Wondwossen GA, Dupouy-Camet J, Newport MJ, Oliveira CJB, Schlesinger LS, Saif YM, et al. The global one health paradigm: challenges and opportunities for tackling infectious diseases at the human, animal, and environment interface in low-resource settings. *PLoS Negl Trop Dis*. (2014) 8:e3257. doi: 10.1371/journal.pntd.0003257
13. Cleaveland S, Sharp J, Abela-Ridder B, Allan KJ, Buza J, Crump JA, et al. One health contributions towards more effective and equitable approaches to health in low-and middle-income countries. *Philos Trans R Soc B Biol Sci*. (2017) 372:20160168. doi: 10.1098/rstb.2016.0168
14. Chatterjee P, Kakkar M, Chaturvedi S. Integrating one health in national health policies of developing countries: India's lost opportunities. *Infect Dis Poverty*. (2016) 5:87. doi: 10.1186/s40249-016-0181-2
15. Oliveira CMd, Cruz MM. Sistema de Vigilância em Saúde no Brasil: avanços e desafios. *Saúde em Debate*. (2015) 39:255–67. doi: 10.1590/0103-110420151040385
16. World Health Organization. *Joint external evaluation tool: International Health Regulations*, (2005). Geneva: World Health Organization (2018).
17. Schwind JS, Gilardi KVK, Beasley VR, Mazet JAK, Smith WA. Advancing the 'One Health' workforce by integrating ecosystem health practice into veterinary medical education: the envirovet summer institute. *Health Educ J.* (2016) 75:170–83. doi: 10.1177/0017896915570396
18. Vieira, E. S.de S. *Defesa Agropecuária e Inspeção de Produtos de Origem Animal: uma Breve Reflexão sobre a Operação Carne Fraca e Possíveis Contribuições ao Aprimoramento dos Instrumentos Normativos Aplicáveis ao Setor.* Brasília: Núcleo de Estudos e Pesquisas/CONLEG/Senado, Março/2017 (Texto para Discussão n° 230).
19. Filho, ODAR. O papel do Vigiagro na prevenção da introdução de pragas quarentenárias no Brasil. *Anais do Seminário Internacional sobre Pragas Quarentenárias Florestais*. (2012). p. 43.
20. Brasil. *Lei N° 8.171. 1991 January 17*. Available online at: http://www.planalto.gov.br/ccivil_03/leis/l8171.htm (accessed March 25, 2021).
21. Brasil. *Lei N° 6.259. 1975 October 30.* Available online at: http://www.planalto.gov.br/ccivil_03/leis/l6259.htm (accessed March 25, 2021).
22. CONASS. *Nota Técnica 02. 2014*. Available online at: https://www.conass.org.br/wp-content/uploads/2014/02/NT-02-2014-Zoonoses.pdf (accessed March 25, 2021).
23. Ministério da Saúde do Brasil. *Portaria N° 1430. 2018 June 11*. Available online at: http://bvsms.saude.gov.br/bvs/saudelegis/gm/2018/prt1430_12_06_2018.html (accessed March 25, 2021).
24. Ministério da Saúde do Brasil. *Portaria N° 1.823. 2012 August 23.* Available online at: http://bvsms.saude.gov.br/bvs/saudelegis/gm/2012/prt1823_23_08_2012.html (accessed March 23, 2021).
25. Ministério da Saúde do Brasil. *Portaria N° 1.339. 1999 November 18*. Available online at: http://bvsms.saude.gov.br/bvs/saudelegis/gm/1999/prt1339_18_11_1999.html (accessed March 23, 2021).
26. Ministério da Saúde do Brasil. *Portaria N° 2.914. 2011 December 12.* Available online at: https://bvsms.saude.gov.br/bvs/saudelegis/gm/2011/prt2914_12_12_2011.html (accessed March 23, 2021).
27. Diário oficial da União. *Instrução Normativa N° 20. 2020 March 13.* Available online at: https://www.in.gov.br/en/web/dou/-/instrucao-normativa-n-20-de-13-de-marco-de-2020-247887393 (accessed March 25, 2021).
28. Fundação Nacional de Saúde. Guia de vigilância ambiental em saúde/Fundação Nacional de Saúde. 2002. Brasília
29. Brasil. *Lei N° 8.171. 1991 January 17*. Available online at: http://www.planalto.gov.br/ccivil_03/leis/l8171.htm (accessed March 25, 2021).
30. Brasil. *Decreto N° 30.691. 1952 March 29*. Available online at: http://www.planalto.gov.br/ccivil_03/decreto/1950-1969/d30691.htm (accessed March 25, 2021).
31. Brasil. *Lei N° 6.198. 1974 December 26*. Available online at: http://www.planalto.gov.br/ccivil_03/leis/1970-1979/L6198.htm (accessed March 25, 2021).
32. Brasil. *Lei N° 7.802. 1989 July 11*. Available online at: http://www.planalto.gov.br/ccivil_03/leis/l7802.htm (accessed March 25, 2021).
33. Brasil. *Lei N° 7.608. 1988 November 8*. Available online at: http://www.planalto.gov.br/ccivil_03/leis/1980-1988/l7678.htm (accessed March 25, 2021).
34. Brasil. *Lei N° 8.918. 1994 July 14*. Available online at: http://www.planalto.gov.br/ccivil_03/leis/l8918.htm (accessed March 25, 2021).
35. Brasil. *Lei N° 24.114. 1934 April 12*. Available online at http://www.planalto.gov.br/ccivil_03/decreto/1930-1949/d24114.htm (accessed March 25, 2021).
36. Ministério da Agricultura, Pecuária e Abastecimento. *Instrução Normativa N°51. 2011 November 4*. Available online at: https://www.gov.br/agricultura/pt-br/assuntos/insumos-agropecuarios/insumos-pecuarios/alimentacao-animal/arquivos-alimentacao-animal/legislacao/instrucao-normativa-no-51-de-4-de-novembro-de-2011.pdf/view (accessed March 25, 2021).
37. Diário Oficial da União. *Instrução Normativa N° 91. 2020 September 18*. Available online at: https://www.in.gov.br/en/web/dou/-/instrucao-normativa-n-91-de-18-de-setembro-de-2020-278692423 (accessed March 25, 2021).
38. Ministério da Agricultura, Pecuária e Abastecimento. *Instrução Normativa N° 6. 2018 January 16*. Available online at: https://www.gov.br/agricultura/pt-br/assuntos/laboratorios/credenciamento-e-laboratorios-credenciados/legislacao-metodos-credenciados/diagnostico-animal%20arquivos/InstruoNormativaMAPAn6de16dejaneirode2018 AprovadaasDiretrizesGeraisparaPreveno...doMORMO.pdf/view (accessed March 25, 2021).
39. Secretaria de Agricultura e Abastecimento do Estado de São Paulo. *Portaria 193. 1994 September 19*. Available online at: https://www.defesa.agricultura.sp.gov.br/legislacoes/portaria-mapa-193-de-19-09-1994,369.html (accessed March 25, 2021).
40. Diário Oficial da União. *Instrução Normativa N° 10. 2017 March 3*. Available online at: <https://www.in.gov.br/materia/-/asset_publisher/Kujrw0TZC2Mb/content/id/19124587/do1-2017%E2%80%9306-20-instrucao-normativa-n-10-de-3-de-marco-de-2017%E2%80%9319124353 (accessed March 25, 2021).
41. Agência Estadual de Defesa Sanitária Animal e Vegetal do Mato Grosso do Sul. *Programa Nacional de Sanidade de Caprinos e Ovinos*. (2020). Available online at: https://www.iagro.ms.gov.br/programa-nacional-de-sanidade-caprinos-e-ovinos-pnsco/ (accessed March 25, 2021).
42. Ministério da Agricultura, Pecuária e Abastecimento. *Instrução Normativa N° 5. 2000 March 31*. Available online at: https://www.gov.br/agricultura/pt-br/assuntos/inspecao/produtos-vegetal/legislacao-1/biblioteca-de-normas-vinhos-e-bebidas/instrucao-normativa-no-5-de-31-de-marco-de-2000.pdf/view (accessed March 25, 2021).
43. Diário Oficial da União. *Instrução Normativa N° 16. 2018 May 8*. Available online at: https://www.in.gov.br/materia/-/asset_publisher/Kujrw0TZC2Mb/content/id/19599014/do1-2018-06-07-instrucao-normativa-n-16-de-8-de-maio-de-2018-19598923 (accessed March 25, 2021).
44. Ministério da Agricultura, Pecuária e Abastecimento. *Instrução Normativa MAPA N° 44. 2007 October 02*. Available onine at: https://www.gov.br/agricultura/pt-br/assuntos/sanidade-animal-e-vegetal/saude-animal/programas-de-saude-animal/febre-aftosa/documentos-febre-aftosa/instrucao-normativa-mapa-no-44-de-02-de-outubro-de-2007.pdf/view (accessed March 25, 2021).
45. Brasil. *Lei N° 9.782.* (1999). Available online at: http://www.planalto.gov.br/ccivil_03/leis/l9782.htm (accessed March 25, 2021).

46. Queiroz ACL, Cardoso LSM, Silva SCF, Heller L, Cairncross S. Programa Nacional de Vigilância em Saúde Ambiental Relacionada à Qualidade da Água para Consumo Humano (Vigiagua): lacunas entre a formulação do programa e sua implantação na instância municipal. *Saúde e Sociedade*. (2012) 21:465–78. doi: 10.1590/S0104-12902012000200019
47. Souza GDS, Costa LCAD, Maciel AC, Reis FDV, Pamplona YDAP. (2017). Presença de agrotóxicos na atmosfera e risco à saúde humana: uma discussão para a Vigilância em Saúde Ambiental. *Ciência Saúde Coletiva*. (2017) 22:3269–80. doi: 10.1590/1413-812320172210.18342017
48. Augusto, LGDS. Saúde e vigilância ambiental: um tema em construção. *Epidemiologia e Serviços de Saúde*. (2003) 12:177–87. doi: 10.5123/S1679-49742003000400002
49. De Freitas Guimarães F, Baptista AAS, Machado GP, Langoni H. Ações da vigilância epidemiológica e sanitária nos programas de controle de zoonoses. *Veterinária e Zootecnia*. (2010) 17:151–62.
50. Jorcelino TM, de Rezende ME, Silva MS. O sistema de vigilância agropecuária internacional e de vigilância em saúde ambiental no Distrito Federal. In *Embrapa Recursos Genéticos e Biotecnologia-Resumo em anais de congresso* (ALICE). Brasilia: Distrito Federal. (2020) 2:2020.
51. Pinheiro TMM, Machado JMH, Ribeiro FSN. A vigilância em saúde do trabalhador. In: *Conferência Nacional de Saúde do Trabalhador*. Brasilia: Distrito Federal. (2005).
52. Portal Brasileiro de Dados Abertos. *Ministério da Agricultura, Pecuária e Abastecimento - MAPA*. (2019). Available online at: http://dados.gov.br/organization/about/ministerio-da-agricultura-pecuaria-e-abastecimento-mapa (accessed September 21, 2020).
53. Ministério da Agricultura, Pecuária e Abastecimento - MAPA. *Programa Nacional de Sanidade Avícula (PNSA)*. (2020). Available online at: http://antigo.agricultura.gov.br/assuntos/sanidade-animal-e-vegetal/saude-animal/programas-de-saude-animal/pnsa/programa-nacional-de-sanidade-avicola-pnsa (accessed September 21, 2020).
54. Agência Estadual de Defesa Sanitária Vegetal e Animal do Mato Grosso do Sul - IAGRO. *Programa Nacional de Controle da Raiva dos herbívoros e Outras Encefalopatias - PNCERH*. (2019) Available online at: https://www.iagro.ms.gov.br/programa-nacional-de-controle-da-raiva-dos-herbivoros-e-outras-encefalopatias-pncerh/#:∼:text=O%20Programa%20Nacional%20de%20Controle,vigil%C3%A2ncia%20epidemiol%C3%B3gica%20e%20outros%20procedimentos (accessed September 21, 2020).
55. Tilocca B, Soggiu A, Musella V, Britti D, Sanguinetti M, Urbani A, et al. Molecular basis of COVID-19 relationships in different species: a one health perspective. *Microb Infect.* (2020) 22:218–20. doi: 10.1016/j.micinf.2020.03.002
56. Menna LF, Santaniello A, Todisco M, Amato A, Borrelli L, Scandurra C, et al. The Human-animal relationship as the focus of animal-assisted interventions: a one health approach. *Int J Environ Res Public Health.* (2019) 16:3660. doi: 10.3390/ijerph16193660
57. O'Brien MK, Macy W, Pelican K, Perez AM, Errecaborde KM. Transforming the One Health workforce: lessons learned from initiatives in Africa, Asia, and Latin America. *Rev Sci Tech*. (2019) 38:239–50. doi: 10.20506/rst.38.1.2956
58. Organização Pan-Americana da Saúde. *Ministério da Saúde EpiSUS – "Além das Fronteiras." Contribuindo para o Fortalecimento da Epidemiologia Aplicada aos Serviços do SUS*. Brasília: OPAS, Ministério da Saúde (2015).
59. Teixeira CF, Paim JS, Vilasbôas AL. SUS, modelos assistenciais e vigilância da saúde. *Fundamentos da vigilância sanitária. Inf Epidemiol Sus.* (1998) 7:7–28.
60. Ministério da Agricultura, Pecuária e Abastecimento - MAPA. *Sanidade de Equídeos (2017).* Available online at: https://www.gov.br/agricultura/pt-br/assuntos/sanidade-animal-e-vegetal/saude-animal/programas-de-saude-animal/sanidade-de-equideos (accessed September 21, 2020).
61. Defesa Agropecuária do Estado de SP. *Programa Estadual de Controle e Erradicação da Brucelose e Tuberculose Animal (PECEBT)*. (2020). Available online at: https://www.defesa.agricultura.sp.gov.br/www/programas/?/sanidade-animal/programa-estadual-de-controle-e-erradicacao-da-brucelose-e-tuberculose-animal-pecebt-sp/&cod=59#:$\sim$:text=O%20Programa%20Nacional%20de%20Controle,promover%20a%20competitividade%20da%20pecu%C3%A1ria (accessed September 21, 2020).
62. Freitas MTDD. *Atuação do Médico Veterinário na Vigilância Agropecuária Internacional (VIGIAGRO)* (Bachelor's thesis). Departamento de Medicina Veterinária, Universidade Federal Rural de Pernambuco, Recife, Brasil (2018).
63. Mulder AC, Kroneman A, Franz E, Vennema H, Tulen AD, Takkinen J, et al. HEVnet: a One Health, collaborative, interdisciplinary network and sequence data repository for enhanced hepatitis E virus molecular typing, characterization and epidemiological investigations. *Eurosurveillance*. (2019) 24:1800407. doi: 10.2807/1560-7917.ES.2019.24.10.1800407
64. Mitchell ME, Alders R, Unger F, Nguyen-Viet H, Le TTH, Toribio JA. The challenges of investigating antimicrobial resistance in Vietnam-what benefits does a One Health approach offer the animal and human health sectors? *BMC Public Health*. (2020) 20:1–12.
65. Johnson J, Howard K, Wilson A, Ward M, Gilbert GL, Degeling C. Public preferences for One Health approaches to emerging infectious diseases: a discrete choice experiment. *Soc Sci Med*. (2019) 228:164–71. doi: 10.1016/j.socscimed.2019.03.013
66. Dente MG, Riccardo F, Bolici F, Colella NA, Jovanovic V, Drakulovic M, et al. Implementation of the one health approach to fight arbovirus infections in the Mediterranean and Black Sea region: assessing integrated surveillance in Serbia, Tunisia, and Georgia. *Zoonoses Public Health*. (2019) 66, 276–87. doi: 10.1111/zph.12562
67. Garcia SN, Osburn BI, Cullor JS. A one health perspective on dairy production and dairy food safety. *One Health*. (2019) 7:100086. doi: 10.1016/j.onehlt.2019.100086
68. MAPA- Ministério da Agricultura, Pecuária e Abastecimento/Gabinete do Ministro. *PORTARIA N° 562. 2018 April 11*. MAPA- Ministério da Agricultura, Pecuária e Abastecimento/Gabinete do Ministro
69. World Health Organization. *One Health*. (2017). Available online at: https://www.who.int/news-room/q-a-detail/one-health (accessed August 15, 2020).
70. González-Bustamante B. Evolution and early government responses to COVID-19 in South America. *World Dev*. (2021) 137:105180. doi: 10.1016/j.worlddev.2020.105180
71. Jorge DCP, Rodrigues MS, Silva MS, Cardim LL, da Silva NB, Silveira IH, et al. Assessing the nationwide impact of COVID-19 mitigation policies on the transmission rate of SARS-CoV-2 in Brazil. *medRxiv*. (2021) 2021:2020–06. doi: 10.1101/2020.06.26.20140780
72. Lasco G. Medical populism and the COVID-19 pandemic. *Global Public Health*. (2020) 15:1417–29. doi: 10.1080/17441692.2020.1807581
73. Campos, CEA. O desafio da integralidade segundo as perspectivas da vigilância da saúde e da saúde da família. *Ciência Saúde Coletiva*. (2003) 8:569–84. doi: 10.1590/S1413-81232003000200018
74. Monken M, Barcellos C. Vigilância em saúde e território utilizado: possibilidades teóricas e metodológicas. *Cadernos de Saúde Pública*. (2005) 21:898–906. doi: 10.1590/S0102-311X2005000300024

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Public Health

OPINION
published: 04 June 2021
doi: 10.3389/fpubh.2021.618234

A Concrete Example of the One Health Approach in the Brazilian Unified Health System

*Paulo César A. Souza[1], Maria Cristina Schneider[2,3], Margarida Simões[4,5], Ana Glória Fonseca[6] and Manuela Vilhena[4,5]**

[1] Department of Epidemiology and Public Health, Veterinary Institute, Federal Rural University of Rio de Janeiro, Rio de Janeiro, Brazil, [2] Department of International Health, School of Nursing and Health Studies, Georgetown University, Washington, DC, United States, [3] Institute of Collective Health Studies, Federal University of Rio de Janeiro, Rio de Janeiro, Brazil, [4] Mediterranean Institute for Agriculture, Environment and Development (MED), University of Évora, Évora, Portugal, [5] Department of Veterinary Medicine, Sciences and Technology School, University of Évora, Évora, Portugal, [6] Department of Public Health, NOVA Medical School, NOVA University of Lisbon, Lisbon, Portugal

Keywords: One Health, health systems, primary care, transdisciplinarity, surveillance, Latin America

OPEN ACCESS

Edited by:
Christina Pettan-Brewer, University of Washington, United States

Reviewed by:
Simon Rodrigo Rüegg, University of Zurich, Switzerland

***Correspondence:**
Manuela Vilhena
mmcv@uevora.pt

Specialty section:
This article was submitted to Planetary Health, a section of the journal Frontiers in Public Health

***Received:** 16 October 2020*
***Accepted:** 16 March 2021*
***Published:** 04 June 2021*

Citation:
Souza PCA, Schneider MC, Simões M, Fonseca AG and Vilhena M (2021) A Concrete Example of the One Health Approach in the Brazilian Unified Health System. Front. Public Health 9:618234. doi: 10.3389/fpubh.2021.618234

INTRODUCTION

The vision that we are all connected in this world is not new. However, to respond to the current challenges the world is facing, an integrated vision where humans, animals, and environment are linked has never been so important (1). Coronavirus disease 2019 (COVID-19) is the most recent example of the complex threats of emerging infectious diseases. El Zowalaty and Järhult (2) discuss the COVID-19 outbreak in a *One Health* context, highlighting the need for the implementation of this approach to improve human health and reduce the emergence of pandemic viruses.

The definition of *One Health* as an "effort to collaborate across multiple disciplines on the local, national, and global level to achieve optimal health for people, animals, and the environment" (3) implies that multidisciplinary approaches in research, education, varied services, and policies could support evidence-based decision-making in health and help build different solutions for challenges in the animal–human–ecosystem interface.

For some countries, the collaboration among disciplines and sectors is already a reality as is the case of Brazil. From the 1970's with the National Rabies Program, created by an agreement between the Ministry of Health and the Ministry of Agriculture, data from both sectors started to be shared, and cases in humans, dogs, other domestic animals, and wild animals were treated in a joint effort (1). In the 1980's, some experiences of multidisciplinary residences in Primary Health Care were created just after Alma-Ata enabled the participation of different professionals to work side by side in special projects in low-income areas (4). However, it was in the 1990's, with the creation of the Brazilian Unified Health System (Sistema Único de Saúde—acronyms SUS in Portuguese), based on a strong emphasis on Primary Health Care, that the opportunity for diverse professionals, namely, veterinary doctors, to become part of a multidisciplinary team came through, mostly at the local level. Altogether, SUS can be considered as a good and practical example of the *One Health* approach in Latin America.

SUBSECTIONS RELEVANT FOR THE SUBJECT

The knowledge and performance of Veterinary Medicine as part of the health professions in Brazil, namely, in the *One Health* approach, is an experience to be shared. The SUS (5) is the practical evidence of a State policy, which operates in all areas of health, from primary care to high complexity healthcare services. Among the policies of the SUS in Primary Care, the Family Health

Strategy (FHS) is a focal point throughout the entire Brazilian territory, with local coordination in the municipalities; and whose basic team is formed by a family medical doctor, a nurse, a nursing assistant, and community health agents working in a given territory (6).

In 2008, extended multidisciplinary teams were created involving more professions to support the Health Centers (in Portuguese "Núcleos de Apoio às Equipes da Estratégia da Saúde da Família"—NASF) (7). These teams formed by several health professionals, such as psychologists, occupational therapists, and veterinary doctors, support a certain number of NASF. The selection of the professionals within the NASF is done according to the epidemiological reality of the territory to be worked by each health team.

In Brazil, the veterinarian is recognized as a health professional by both the Ministry of Health and the Ministry of Education since 1993 and has been part of the NASF Teams since 2011 (8), working in close collaboration with physicians and other health professionals, bringing to the operation the concept and practicality of *One Health* (1). These multidisciplinary teams working at the local level are part of the objectives of Health Surveillance and its components of Epidemiological, Sanitary and Environmental Surveillance (9). Hence, each NASF team has different joint activities, such as identification of potential zoonosis emergency, joint outbreak investigation, discussion of specific zoonotic cases (food-related or animal/vector-borne), home visits to follow-up events in the animal–human interface, identification and control of vectors and pests in the area and inside homes, analysis of environmental changes caused by man and natural disasters, and defining prevention and control strategies. The NASF teams also collaborate in the preparation of health education and communication strategies for the local communities, through team discussions, performing interdisciplinary actions, and developing shared responsibility (10).

In regard to the COVID-19 pandemic (caused by the infection of severe acute respiratory syndrome coronavirus 2, SARS-CoV-2), veterinarians have been strongly involved throughout the country at the municipal level, mainly in health surveillance, as well as in health education, mostly in both food safety and food production guidance. Besides, veterinarians were considered as part of the program on strategic action "Brazil Counts With Me—Health Professionals," focused on the training and registration of health professionals for the detection and epidemiosurveillance of COVID-19 patients (11).

Altogether, the recognition as a health professional and the work developed by veterinarians in the SUS, in Brazil reveal that this experience can serve as an example to other countries in the Latin Americas and in other parts of the world. Furthermore, Queenan et al. (12) reveals unique experiences and advantages of integrated human and animal health services, namely, National Services of Italy, Canada, and Kenya. All these examples feature collaborative efforts and strategies for others to pursue.

DISCUSSION

For several years, the United Nations and the European Union, through different mechanisms, have been driving various initiatives to implement the *One Health* approach (13).

This awareness prompted a bibliographic review uncovering more than 250 articles related to *One Health* worldwide, many of them related to the concept and the history; however, publications referring to the application of the concept increased in number after 2013 (1). The turning point for the application of the *One Health* concept was the preparation for the potential avian influenza H5N1 pandemic around 2005 and 2006, when several official documents addressing the importance of intersectoral collaboration and joint preparedness plans were made in the Americas, Southeast Asia, and other parts of the world (1). Yet again, another influenza pandemic occurred in 2009 (H1N1 viral isolate) for which the previous joint preparedness plans greatly contributed to manage the disease dissemination. Together, these plans and evolving versions enabled prompt and adequate responses to other zoonotic threats.

The first declaration of a Public Health Emergency of International Concern (PHEIC), since a new version of the International Health Regulations (IHR) was in place (2005), was pronounced during the H1N1 pandemic when a stronger global cooperation for risk assessment and capacity-building was deemed crucial. Alongside, advocating for a *One Health* approach to better prevent, detect, and respond to any pandemic potential threat (14).

The coronaviruses (CoV) with animal origin represent a continuous pandemic threat to global health security, as previous coronavirus crises can be traced back to 2003 with the emergence of SARS-CoV and also in 2012 when the Middle East Respiratory Syndrome coronavirus (MERS-CoV) created a novel challenge (2). Although concrete evidence is not available, other hypothesis based on the mutation rate of a specific viral gene and molecular clock analysis considers that interspecies CoV infection, crossing from bovine to humans, may have occurred in the late 1890's (15). This possible CoV outbreak caused a worldwide disruption and maintains the infamous designation of the Great Russian Flu pandemic.

With respect to the human–animal health interconnectedness, the World Health Organization defines a zoonosis as any infection naturally transmissible from vertebrate animals to humans (16) and has already included the COVID-19 pandemic, caused by SARS-CoV-2, in these zoonotic diseases class. However, and according to Haider et al. (17), no animal reservoir has yet been identified, considering this classification as premature. Haider and collaborators propose that COVID-19 should instead be classified an "emerging infectious disease (EID) of probable animal origin," without compromising the importance of zoonoses and communicable diseases common to humans and animals as potential PHEIC that is well-known for more than 20 years. Forasmuch as the importance of zoonoses, Taylor et al. (18) estimated that around 70% of infectious hazard threats to public health have an interface with animals, confirmed by other studies that have demonstrated the importance of animal/human health interface and suggested the need for more comprehensive research (19).

Remarkably, WHO included the *One Health* approach in evaluations of the country core capacities to implement the IHR (20). The joint evaluation exercise, coordinated by WHO, has been performed by countries and by peer reviewers in the context of the Joint External Evaluation (JEE), in order to evaluate the country core capacities to prevent, detect, and respond to possible PHEIC and include several indicators to evaluate this coordination (21). The most recent example of this assessment is related to COVID-19, a declared PHEIC by WHO, revealing each country/region's capacities and fragilities to address the pandemic and calling out for multisectoral collaborations. This could be considered one step further in the direction of the *One Health* approach and operationalization, setting the goal in truly understanding how animals and humans are linked, based on concrete examples. Noteworthy, it is not a current practice in most countries as demonstrated in the WHO/JEE scores (22).

Transdisciplinary studies and integrative collaboration across research, practice, and society counterparts are needed both to prompt a wholesome perspective (from local to global settings) and to enhance a comprehension of the details intertwined. The term "transdisciplinary health" was tentatively proposed by Assmuth et al. (23) to signify the multidimensional integration across fields relevant for health assurance. And what is the *One Health* approach really about? It is a framework that equates the shared environment affected by the socio-economic interest of humans. A *One Health* concept calls for various disciplines to work together to provide new methods and tools for research and implementation of effective services to support the formulation of norms, regulations, and policies to the benefit of current and future generations. This will improve the understanding of health and disease processes as well as the prediction, detection, prevention, and the control of infectious hazards and other issues affecting health and well-being in the human–animal–ecosystem interface, contributing to the sustainable development goals and to the improvement of equity in the world (1). Public Health depends on it!

AUTHOR CONTRIBUTIONS

All authors contributed for the article with opinions and discussion.

REFERENCES

1. Schneider MC, Munoz-Zanzi C, Min K, Aldighieri S. "One Health" from concept to application in the global world. In: *Oxford Research Encyclopedia of Global Public Health* (2019).
2. El Zowalaty ME, Järhult JD. From SARS to COVID-19: a previously unknown SARS- related coronavirus (SARS-CoV-2) of pandemic potential infecting humans - call for a One *Health* approach. *One Health.* (2020) 9:100124. doi: 10.1016/j.onehlt.2020.100124
3. King LJ, Anderson LR, Blackmore CG, Blackwell MJ, Lautner EA, Marcus LC, et al. Executive summary of the AVMA One Health Initiative Task Force report. *J Am Vet Med Assoc.* (2008) 233:259–61. doi: 10.2460/javma.233.2.259
4. Schneider MC. Saúde comunitária, saneamento e participação comunitária na melhoria da qualidade de vida: relato de uma experiência. *Arquivos Med Prev.* (1984) 6:47–54.
5. Presidência da República. *Lei nº 8.080, de 19 de setembro de 1990*. Planalto, Casa Civil, Subchefia Para Assuntos Jurídicos (1990). Available online at: http://www.planalto.gov.br/ccivil_03/leis/l8080.htm
6. Ministério da Saúde/Gabinete do Ministro do Brasil. *Saúde da Família*. Ministério Da Saúde (1994). Available online at: https://www.saude.gov.br/artigos/772-acoes-e-programas/saude-da-familia/41285-saude-da-familia
7. Souza PCA, Anjos CB, Pereira LRM, Vallandro MJ, Figueiredo AB, Amora SSA, et al. Médico veterinário, a estratégia de saúde da família e o NASF. *Rev Conselho Federal Med Vet.* (2009) 48:9–14.
8. CRMV-RJ. *Inclusão do Médico Veterinário no Conselho Nacional de Saúde Completa 25 Anos*. CRMV-RJ (2018). Available online at: http://www.crmvrj.org.br/inclusao-do-medico-veterinario-no-conselho-nacional-de-saude-completa-25-anos/
9. Souza PCA, Figueiredo AB, Anjos CB, Pereira LRM, Vallandro MJ, Amora SSA. NASF: do abstrato ao concreto. *Rev Conselho Federal Med Vet.* (2012) 18:69–71. Available online at: https://www.cfmv.gov.br/revista-cfmv-edicao-48-2009/comunicacao/revista-cfmv/2018/10/30/
10. Souza PCA. NASF: uma reflexão após cinco anos. *Rev Conselho Federal Med Vet.* (2016) 69:84–5. Available online at: https://www.cfmv.gov.br/revista-cfmv-edicao-69-2016/comunicacao/revista-cfmv/2018/11/01/
11. Ministério da Saúde/Gabinete do Ministro do Brasil. *Portaria nº. 639, de 31 de Março de 2020*. Brasil: Diário Oficial Da União; Ministério da Saúde Brasil (2020).
12. Queenan K, Garnier J, Nielsen L-R, Buttigieg S, de Meneghi D, Holmberg M, et al. Roadmap to a One Health agenda 2030. *Perspect Agric Vet Sci Nutr Nat Resour.* (2017) 12:1–17. doi: 10.1079/PAVSNNR201712014
13. De Menegui D, de Balogh K, Vilhena M. Experiences of international networks for collaborative education and research using the One Health approach. In: Parodi P, Dottori M, Venturi L, editors. *Quaderni della Società Italiana di Medicina Tropicale e Salute Globale* Rome: Società Italiana di Medicina Tropicale e Salute Globale (SIMET) (2016). p. 33–9.
14. Bennett B, Carney T. Public health emergencies of international concern: global, regional, and local responses to risk. *Med Law Rev.* (2017) 25:223–39. doi: 10.1093/medlaw/fwx004
15. Vijgen L, Keyaerts E, Moës E, Thoelen I, Wollants E, Lemey P, et al. Complete genomic sequence of human coronavirus OC43: molecular clock analysis suggests a relatively recent zoonotic coronavirus transmission event. *J Virol.* (2005) 79:1595–604. doi: 10.1128/JVI.79.3.1595-1604.2005
16. World Health Organization. *Health Topics: Zoonoses*. Zoonoses: Geneva (2020). Available online at: https://www.who.int/news-room/fact-sheets/detail/zoonoses (accessed February 2, 2021).
17. Haider N, Rothman-Ostrow P, Osman AY, Arruda LB, Macfarlane-Berry L, Elton L, et al. COVID-19—zoonosis or emerging infectious disease? *Front Public Health.* (2020) 8:596944. doi: 10.3389/fpubh.2020.596944
18. Taylor LH, Latham SM, Woolhouse MEJ. Risk factors for human disease emergence. *Philos Trans R Soc B Biol Sci.* (2001) 356:983–9. doi: 10.1098/rstb.2001.0888
19. Schneider MC, Aguilera XP, Smith RM, Moynihan MJ, Silva JB Jr, Aldighieri S, et al. Importance of animal/human health interface in potential Public Health Emergencies of International Concern in the Americas. *Rev Panam Salud Publica.* (2011) 29:371–9. doi: 10.1590/S1020-49892011000500011
20. World Health Organization. *International Health Regulations (2005)*. World Health Organization (2016). Available online at: https://www.who.int/ihr/publications/9789241580496/en/#.X4MlNzd04QA.mendeley
21. World Health Organization. *Joint External Evaluation tool (JEE Tool), 2nd Edn. IHR (2005) Monitoring and Evaluation Framework*. World Health Organization (2018). Available online at: https://www.who.int/ihr/publications/WHO_HSE_GCR_2018_2/en/#.X4M0n7zN94M.mendeley (accessed February 1, 2021).
22. Aitken T, Chin KL, Liew D, Ofori-Asenso R. Rethinking pandemic preparation: Global Health Security Index (GHSI) is predictive of COVID-19 burden, but in the opposite direction. *J Infect.* (2020) 81:2. doi: 10.1016/j.jinf.2020.05.001

23. Assmuth T, Chen X, Degeling C, Haahtela T, Irvine KN, Keune H, et al. Integrative concepts and practices of health in transdisciplinary social ecology. *Socio Ecol Pract Res.* (2020) 2:71–90. doi: 10.1007/s42532-019-00038-y

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Public Health

ORIGINAL RESEARCH
published: 10 June 2021
doi: 10.3389/fpubh.2021.649190

Shifting From Sectoral to Integrated Surveillance by Changing Collaborative Practices: Application to West Nile Virus Surveillance in a Small Island State of the Caribbean

Mariana Geffroy [1,2], *Nonito Pagès* [2], *David Chavernac* [2], *Alexis Dereeper* [1,2], *Lydéric Aubert* [3], *Cecile Herrmann-Storck* [4], *Anubis Vega-Rúa* [5], *Sylvie Lecollinet* [6] *and Jennifer Pradel* [1,2]*

[1] CIRAD, UMR, ASTRE, Petit-Bourg, France, [2] ASTRE, CIRAD, INRAE. Univ Montpellier, Montpellier, France, [3] CIRE Antilles, Santé Publique France, Pointe-à-Pitre, France, [4] Centre Hospitalier Universitaire, Department of Bacteriology, Virology and Parasitology, Pointe-à-Pitre, France, [5] Institut Pasteur de Guadeloupe, Laboratory of Vector Control Research, Unit Transmission, Reservoirs and Pathogen Diversity, Les Abymes, France, [6] Anses, Laboratory for Animal Health, UMR1161 Virology, INRAE, Anses, ENVA, Maisons-Alfort, France

Edited by:
Christina Pettan-Brewer,
University of Washington,
United States

Reviewed by:
Maquins Odhiambo Sewe,
Umeå University, Sweden
Gilton Almada,
Universidade Vila Velha, Brazil

***Correspondence:**
Jennifer Pradel
jennifer.pradel@cirad.fr

Specialty section:
This article was submitted to
Planetary Health,
a section of the journal
Frontiers in Public Health

Received: 04 January 2021
Accepted: 11 May 2021
Published: 10 June 2021

Citation:
Geffroy M, Pagès N, Chavernac D, Dereeper A, Aubert L, Herrmann-Storck C, Vega-Rúa A, Lecollinet S and Pradel J (2021) Shifting From Sectoral to Integrated Surveillance by Changing Collaborative Practices: Application to West Nile Virus Surveillance in a Small Island State of the Caribbean. Front. Public Health 9:649190. doi: 10.3389/fpubh.2021.649190

After spreading in the Americas, West Nile virus was detected in Guadeloupe (French West Indies) for the first time in 2002. Ever since, several organizations have conducted research, serological surveys, and surveillance activities to detect the virus in horses, birds, mosquitoes, and humans. Organizations often carried them out independently, leading to knowledge gaps within the current virus' situation. Nearly 20 years after the first evidence of West Nile virus in the archipelago, it has not yet been isolated, its impact on human and animal populations is unknown, and its local epidemiological cycle is still poorly understood. Within the framework of a pilot project started in Guadeloupe in 2019, West Nile virus was chosen as a federative model to apply the "One Health" approach for zoonotic epidemiological surveillance and shift from a sectorial to an integrated surveillance system. Human, animal, and environmental health actors involved in both research and surveillance were considered. Semi-directed interviews and a Social Network Analysis were carried out to learn about the surveillance network structure and actors, analyze information flows, and identify communication challenges. An information system was developed to fill major gaps: users' needs and main functionalities were defined through a participatory process where actors also tested and validated the tool. Additionally, all actors shared their data, which were digitized, cataloged, and centralized, to be analyzed later. An R Shiny server was integrated into the information system, allowing an accessible and dynamic display of data showcasing all of the partners' information. Finally, a series of virtual workshops were organized among actors to discuss preliminary results and plan the next steps to improve West Nile Virus and vector-borne or emerging zoonosis surveillance. The actors are willing to build a more resilient and cooperative network in Guadeloupe with improved relevance, efficiency, and effectiveness of their work.

Keywords: integrated surveillance, social network analysis, One Health, information system, West Nile virus, Guadeloupe (French West Indies)

INTRODUCTION

West Nile Virus (WNV) is the world's most widely spread vector-borne flavivirus (1). It primarily affects wild birds, being its natural reservoirs capable of amplifying the virus and maintain it in nature. High-titer viremias develop within infected reservoir birds, which transmit the virus through a cycle involving several mosquito species from the *Culex* genus (2). In addition, WNV can infect several mammalian, avian, and reptile species considered as "dead-end hosts." WNV (3, 4) is the etiological agent for West Nile Fever in humans, equines, and several bird species, where different disease outcomes of the disease are found, ranging from asymptomatic (in the majority of cases) and mild flu-like illness to severe neurological disease and death (5–7).

WNV was first isolated from the blood of a febrile woman in Uganda in 1937 (3). Initially, the virus was endemic to the African continent and the Middle East with sporadic epidemics in Southern Europe. In the 90s, and even more notably after 2008, more WNV outbreaks were reported in Eastern Europe and the Mediterranean, gaining importance as an emerging and re-emerging pathogen in this region (8).

Several theories suggest that the virus has been mainly spread by migratory wild birds, outside its original distribution range (9, 10). The most striking event regarding WNV diffusion and emergence corresponds to WNV introduction in America from the Middle East in the 90s. A more likely scenario to explain virus introduction in the Americas is through commercial or unintentional transportation of birds or mosquitoes (11).

The New York outbreak marked the first description of WNV on the American continent in 1999 (1), consisting of the onset of severe West Nile Fever cases in horses and humans. Such outbreak was preceded by high numbers of wild bird mortality in the area, putting several public health and veterinary organizations on alert. Subsequently, WNV dispersed northward to Canada and southward to Central America, South America, and the Caribbean (9) following migratory flyways, being the Caribbean situated along the Atlantic and the Mississippi flyways connecting North and South America.

The first detection of WNV within the Caribbean was reported in 2001; a man from the Cayman Islands without a recent travel history (3). In 2002 several islands reported antibody-positive animals, confirming that the virus had arrived in the Dominican Republic, Guadeloupe, Jamaica, and Eastern Mexico (12–14). Viral strains identified in the area were the same as those found in Florida (12). The following year, the virus was circulating in Puerto Rico, Cuba, the Bahamas, and by 2004, the virus was identified in Colombia and on the island of Trinidad (14, 15). More recently, in the British Virgin Islands, a WNV isolate sharing more than 99% nucleotide homology with earlier US WNV strains were found on dead wild birds (Caribbean flamingos, *Phoenicopterus ruber ruber*), confirming that the outbreak resulted from the geographic expansion of US strains (16). Moreover, seropositive equids, both locally bred and imported animals, were found in Saint Kitts and Nevis and Sint Eustatius, meaning WNV was circulating in the Caribbean (17).

In contrast to the situation in North America (7 million WNV human clinical cases recorded since the virus was first detected in the USA), WNV dispersion in Latin America and the Caribbean has been rather silent, without significant bird mortality or clinical manifestations in human and animal populations (11). This has made tracking WNV challenging in the Caribbean region, where the primary information source comes from serological tests. Additionally, there is a high prevalence of other flaviviruses in Central America and the Caribbean; therefore, cross-reactions in serological testing can occur, and positive WNV detections in the area need to be interpreted with care, especially in humans. Lastly, critical wild bird species for virus dispersal and mosquito vector species have not been clearly identified, even though WNV is a public health concern that, due to local meteorological conditions, can be transmitted all year round (10, 18). While the virus has probably become endemic in the Americas, there have been few strains and genomes isolated from outside the USA, with no large WNV outbreaks reported, highlighting the need for further investigation to understand the true burden of WNV in Latin America and the Caribbean (11).

The environmental component is an integral part of the WNV system and is crucial to understand its epidemiological cycle. Several environmental factors - climatic (temperature, rainfall, relative humidity) or other modifications of the habitats or land use can significantly impact vectors and vector-borne disease distribution (19–21). They may indeed play a significant role in the life cycle, distribution, vector and host density (22), and on vector competence (23, 24), influencing the likelihood of vector-virus-host interactions.

Guadeloupe (16°15' N, 61°35' W) is a French Overseas Territory located in the Lesser Antilles in the Eastern Caribbean Sea (22). Differential patterns in precipitation, temperatures, and the fertility of volcanic soil have created highly diverse ecosystems: (i) tropical semi-deciduous forests, (ii) tropical rainforests, and (iii) several types of wetlands like mangroves, lagoons, brackish and freshwater ponds, and swamplands (23, 24). Urbanization and agricultural development also have degraded natural ecosystems. All of these elements can foster WNV vector and host populations. Guadeloupe's main activities are agriculture (banana, sugar cane), and tourism, relying on connections with neighboring Caribbean countries, North America, and France, thus increasing the risks of pathogen introduction, turning Guadeloupe into a hotspot for the emergence and spread of biological hazards.

More than 33 mosquito species are present in Guadeloupe (25, 26), and several vector-borne disease outbreaks (dengue, Zika, and chikungunya) have been recorded in the last two decades. Also, Guadeloupe has about 60 nesting bird species and at least 120 migrant or vagrant bird species (27), making

Abbreviations: ANSES, French Agency for Food, Environmental and Occupational Health & Safety; ARS, Regional Health Agency; CHU, Center Hospitalier Universitaire; CIRAD, French Agricultural Research Center for International Development; CIRE, Interregional Epidemiology Unit of Antilles-Guyane; DAAF, Direction de l'Alimentation, l'Agriculture et la Forêt; IPG, Institute Pasteur de Guadeloupe; IS, Information System; OFB, French Agency for Biodiversity; SNA, Social Network Analysis; SPF, Santé Publique France; WNND, West Nile Neuroinvasive Disease; WNV, West Nile Virus; WNIS, West Nile Information System.

the introduction of WNV through migratory species a real possibility. In July 2002, WNV was identified for the first time in Guadeloupe via serological investigations (ELISA and sero neutralization tests) that revealed the presence of IgG and IgM antibodies against WNV in horses and chicken samples with seroprevalence rates ranging from 2.8 to 10.4%. Six months later, horses' prevalence rate increased up to 50%; which was probably linked to the first WNV incursion in Guadeloupe a couple of months earlier (13). After the first detection of WNV in Guadeloupe, a multidisciplinary surveillance was set up to improve the knowledge of the virus distribution and its burden in human and animal populations of Guadeloupe. As part of the WNV surveillance programs, information campaigns were implemented to increase awareness in physicians, hunters, veterinarians, the general public, and horse and poultry owners. The transmission of WNV decreased dramatically during 2003 and 2004 in horses and poultry. Neither clinical cases in equines nor neurological disorder linked to WNV infections in humans has been reported (18). New seroconversions were detected on horses afterward between September 2007 and August 2008 and between January 2011 and March 2013 (23, 25). Furthermore, mosquito surveillance was set up early in 2015 to monitor mosquito population dynamics in two WNV equine and chicken sentinel sites and to identify the vector species involved (25). Despite these efforts, WNV has never been isolated from mosquitoes, horses, nor bird samples collected in Guadeloupe (28). Additionally, WNV bird mortality was never observed, possibly due to (a) the existence of few susceptible bird species in the territory, (b) hypothetical low vector competence, and (c) possible co-circulation of other flaviviruses (13, 29). In humans, out of nine suspected cases from the Center Hospitalier Universitaire of Pointe-à-Pitre (CHU), none were confirmed as WNV cases, with symptoms that could be attributed to other pathologies. However, it is well-recognized that the causative pathogens of infectious encephalitis in humans in tropical areas are poorly known and investigated (30). Usually, WNV is screened in patients and animals developing neurological symptoms, so mild West Nile Fever (WNF) cases can often go under-recognized (3). Nowadays, WNV surveillance continues in Guadeloupe but mainly involves the veterinary and the entomological components while the actors of the human health sector are in charge of surveillance and control of other human flaviviruses, like dengue and Zika. Most of the WNV surveillance activities in Guadeloupe are sectorial and do not involve regular communication across sectors. After many years of a disassociate surveillance, the actors decided to implement a "One Health" approach to improve WNV surveillance and work more effectively and efficiently together.

WNV surveillance exemplifies how "One Health" approaches can be useful and necessary to understand and create methods for establishing more resilient disease surveillance and control. "One Health" is frequently described as a multidisciplinary and collaborative approach working locally, regionally, and globally to prevent and mitigate risks that originate from the animal-human-environment interface in order to attain optimal health and well-being for everyone (31, 32). There is a particular emphasis on teamwork and communication across disciplines, communities, and sectors, where health problems can be addressed by examining their multiple dimensions. Surveillance using a "One Health" approach, also known as Integrated or "One Health" surveillance, happens when surveillance is organically harmonized, allowing actors and stakeholders from different backgrounds and organizations to work together to control, for instance, a zoonotic pathogen. It consists of systematic collection, validation, analysis, interpretation, and dissemination of information collected on humans, animals, and the environment to inform decisions for more effective, evidence- and system-based health interventions (33). Integrated surveillance aims to share data, providing faster detection and better disease control, compared to sectorial pathogen surveillance, where each sector works only with its data and reacts individually to the outcomes. Benefits have been seen in both disease management efficiency and cost reduction by sharing logistics, human resources, and splitting expenses between institutions. However, joint surveillance is not a problem-free approach due to issues related to barriers for information sharing, unclear responsibilities, privacy regulations, or structural barriers inside organizations adding the lack of communication between actors (33–35). Implementing joint information systems seems necessary and has already been enacted successfully in other parts of the world (36–38).

The application of "One Health" programs aims at offering early detection of circulating WNV in wildlife, mosquitoes, sentinel animals, or confirmed clinical cases. If WNV is detected, human health institutions and authorities are informed and can, in turn, implement vector control measures and preventive activities in the population, thus reducing the number of human infections (38).

Surveillance programs rest on top of two essential pillars: (i) the coordination of the people or organizations in charge of the surveillance and (ii) the establishment of an efficient data exchange network that allows actors from the field to the decision making levels to have quick access to data and information when required (39). The implementation and use of information systems (IS)—defined as "the set of processes implemented to ensure data management" with clear rules concerning sharing mechanisms—is essential for integrated "One Health" surveillance programs.

This article aims to share the experience of Guadeloupean partners who initiated a shift in collaboration practices based on the "One Health" approach applied to the WNV surveillance system in Guadeloupe. This led to the creation of an integrated information system for disease surveillance. Also, a social network analysis (SNA) was implemented in which the relationships, strengths, and weaknesses of the network could be identified, and possible recommendations were made to improve cross-sectoral collaborations and better tackle future emerging zoonotic threats in Guadeloupe in the long-term.

MATERIALS AND METHODS

Four participatory workshops were organized between February and November 2020 to which all actors implicated in

WNV surveillance were invited. The first two workshops (organized in February and March 2020) had a capacity-building component on Information Systems (IS), databases, and data visualization using R Shiny. The last two workshops (organized in November 2020) focused on testing the new tools, discussing recommendations, and developing a strategic plan toward a more sustainable network.

Development of the Information System

During the first workshop, the EVASYON method developed by Chavernac, was used following several steps: (i) identification, mapping and role (data collection, centralization, analysis, information sharing) of all the actors and description of surveillance data flow at the regional (Guadeloupe), national (French), and international levels; (ii) identification of current IT resources and data, and creation of a data catalog; and (iii) a comprehensive evaluation of the state of available information and future planning to create an IS for WNV (WNIS) in Guadeloupe. At the end of the workshop, participants agreed on preliminary technical specifications for the creation of an IS (sections, functionalities, users' rights) that would allow participants to collect, store and share data among all participants and organizations that have a role in WNV surveillance, depending on the participants' needs and interests.

A detailed document with all the technical requirements and specifications was prepared by a small working group using an online editable platform to facilitate collaboration with the developer (Google Docs). The WNIS prototype was developed using php/MySQL and the Rapid Application Development of php Runner (https://xlinesoft.com/phprunner). It was adapted to main users' comments and needs shared throughout 2020. A final prototype version was presented to the broader group of WN surveillance actors (veterinarians, DAAF, Santé Publique France, CHU, IPG…) for discussion through another participatory workshop held in November 2020. Improvements have been made to prepare a beta version that will run in 2021 for testing and validation. The final IS will be developed and transferred to a local server using the feedback on its use after several months of field WNV surveillance.

Data Catalog

Information on the WNV surveillance activities conducted since 2002 by the various institutions was collected, emphasizing that data, reports, and knowledge would be used to develop and test the new WNIS.

The data catalog was prepared using the Dublin Core (40), a metadata structure used to classify electronic resources with a brief description of their content and characteristics. In this case, using the Dublin Core allowed easy creation of the catalog and, in the future, facilitates the proper maintenance, management, and use of existing resources.

Use of R Shiny for Data Visualization

During the second workshop, partners interested in tool development and conception were trained on R Shiny, an application for dynamic and interactive data visualization entered in the web interface to capture and manage surveillance data reports from the WNIS. Indeed, an attractive and dynamic display of information to the partners and the general audience is one of the goals of this integrated WNV surveillance system. Concurrently to the WNIS development, a graphical and cartographic data visualization web application called VirusTracking was deployed. The application was written in "R" using the Shiny framework. It explores data and information stored in the MySQL database of the IS accessible for the WNV surveillance members from a secured server, and the surveillance databases. It relies on Shiny's reactive programming framework, allowing the communication of results easily via interactive charts, texts, or tables, and compartmentalizes and caches expensive computational stages so that an interactive session does not require calculations and queries to be recomputed unnecessarily. The application is directly connected to the MySQL database and allows the extraction of the information through SQL queries.

Social Network Analysis

Social Network Analysis (SNA) is defined as a "distinctive set of methods used for mapping, measuring, and analyzing the social relationships between people, groups, and organizations" (41, 42). It can be used to evaluate any network, from businesses, governmental institutions to health and ecological systems that involve people and organizations. In general, knowledge of how actors and partners interact with one another helps understand how the information flows between organizations and under what conditions (43).

Given the large number of organizations belonging to different sectors and backgrounds involved in the WNV surveillance in Guadeloupe, an SNA was used to understand the ties and relationships of the actors implicated in WNV surveillance in Guadeloupe and in identifying the levers and barriers that influence teamwork. Relevant recommendations about desirable changes to increase communication and collaboration will be facilitated.

In order to attain the stated objective, a questionnaire was created and piloted to collect information about the connectivity, centrality, and flux of information between actors. The questionnaire consisted of four parts: (a) personal information, (b) network connections and information flow, (c) actions for the future of the network, and (d) current perception of the network. It also allowed the acquisition of information using focused ethnography, a methodology that helps describe a group, its experiences, attitudes, and interactions (44, 45). Actors were asked to describe and give their opinion about the network's current state, challenges, and future actions for improvement.

Face-to-face, telephone, or via ZOOM™, semi-directed interviews were conducted with the actors involved in the surveillance of WNV. Interviews were done both in French or English, depending on the interviewee's confidence and language management level. All the interviews were recorded for later transcription. If interviews were in French, they were transcribed and translated into English for subsequent analysis.

The qualitative analysis of the actors' interviews was carried out using Nvivo, a qualitative data analysis software (QSR International, Release 1.0). For the network mapping,

TABLE 1 | WNV surveillance activities in Guadeloupe.

Component of the WNV surveillance	Organizations involved	Type of surveillance	Description of surveillance activities
Human	CHU Pointe-a-Pitre Interregional Epidemiology Unit of Antilles-Guyane (CIRE) of Santé Publique France (SPF)	Passive	WNV screening in suspected clinical cases: undiagnosed viral encephalitis or meningitis or infections consistent with West Nile Neuroinvasive Disease (WNND). Frequency of data collection: infrequent, highly heterogeneous.
	Regional Health Agency (ARS) National Center of Arboviruses (France)	Serosurvey	Flavivirus screening in pregnant women within the framework of Zika surveillance (2016–2017). West Nile was included in the testing.
Domestic animals (equines and poultry)	Direction de l'Alimentation, l'Agriculture et la Forêt (DAAF) CIRAD Private veterinarians	Active	Use of sentinel equids and chickens to detect WNV circulation. Horses from four sentinel sites were sampled yearly until 2018. Chickens from two sentinel farms were sampled every 15 days between 2013 and 2018 and every 3 months since 2019. Frequency of data collection: regular in chickens some years are missing in horses.
	DAAF CIRAD Private veterinarians	Event-based	WNV screening in suspected clinical cases in equids presenting signs of neurological disease. Frequency of data collection: every year, during the 2nd semester; however, it is not activated correctly every year.
Wild birds	SAGIR network of the OFB CIRAD laboratory	Event-based	Identification of high wild-bird mortality events and testing. Effective in Mainland France. Not operational yet in Guadeloupe.
Wild birds	IPG CIRAD laboratory	Serosurvey	Data collected within the framework of a 2-year project.
Entomological	CIRAD	Active	Mosquito species identification and determination of population dynamics in Guadeloupe. Frequency of data collection: Every 2 weeks since the end of 2014, alternating with the sentinel chicken surveillance in order to be able to detect pools of mosquitoes infected in case of seroconversion observed in poultry.

matrices with actor relationships with one another and their communication level were created. The matrices' analysis was done using R Studio with the following packages: igraph, network, sna, ggraph, visNetwork, threejs, network D3, and ndtv. Map designs were improved using Gephi, an open-source network analysis and visualization software (46).

RESULTS

The interactions among partners evidenced three critical points: (i) a multitude of persons were involved, (ii) a large set of data was disseminated within the different institutions, and (iii) only a few interactions existed between different actors. Additionally, no single formal WNV surveillance exists, but rather, several surveillance activities are carried out by different institutes that communicate poorly with each other.

West Nile Surveillance Organization and Available Information/Data

The WNV surveillance organization in Guadeloupe and the data's location is summarized in **Table 1** and **Figure 1**. Every database included information relevant to individual surveillance objectives, and they were centralized at the French Agricultural Research Center for International Development (CIRAD) for future data analysis.

The primary sources of data came from the following organizations:

CIRAD: Poultry, equine, and mosquito surveillance data. Excel files and Access databases are stored in CIRAD's Laboratory Quality Assurance system and server.

Institute Pasteur of Guadeloupe (IPG): The database of a research project on wild birds was shared. It was organized as a list using the bird capture dates, location, and serological results.

CHU Pointe-à-Pitre: No existing records could be found, but communications were established concerning WNV samplings at the hospital, with concerns about those samples' poor quality, resulting in unreliable results.

Santé Publique France (SPF): A serosurvey of pregnant women was organized in Guadeloupe within the Zika surveillance framework. Several flaviviruses, including WNV, were tested.

The main sources of data were initially organized in separate Microsoft Excel documents. Excel files were further merged by component, completed, harmonized, and validated using the lab result sheets that were delivered to each sampling group. These MS Excel documents were ordered by date, and four MS Excel documents were finalized for each component—equine, birds, humans, and mosquitoes—to prepare future integrated data analysis.

Pilot WNV Information System and R Shiny component

A consensus was reached among the partners to develop a simple WNIS based mainly on the regular sharing of

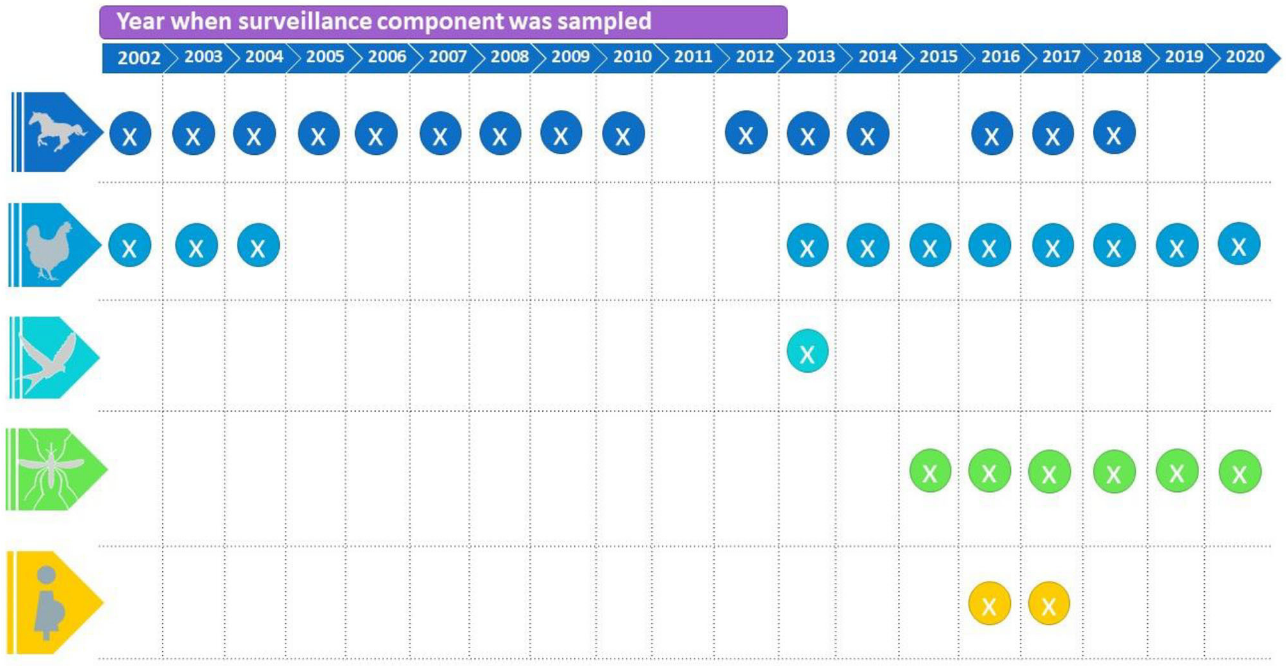

FIGURE 1 | Chronogram of surveillance activities that took place from 2002 to 2020 in horses, poultry, wild birds, mosquitoes, and humans, based on the datasets provided by the partners.

surveillance reports for the different surveillance components (human, equine, domestic poultry). We hypothesized that each organization had databases already in place and that the IS would not attempt to duplicate data entries in a third-party application but rather allow collecting synthesized data. The main actors agreed that the primary information that would be entered and displayed in the WNIS would be: location (commune), component (human, equine, poultry, wild birds), reporting organization, event, number of individuals tested, number of positive (and test used), number of negative, number of deaths (**Figure 2B**). The information would be submitted through monthly to quarterly reports. The information is comparable for all surveillance components allowing easy visualization with automatic data recovery routines with R Shiny. The final prototype is being developed using the latest workshops' outputs with the actors who required additional functionalities such as implementing alert flows to notify partners of WNIS activities alongside access rights management. A local web server hosting the platforms and allowing a dynamic connection between the IS and the R-Shiny visualization interface has yet to be identified before the system is passed in production. In the meantime, it is located in a temporary server in mainland France. The demo version is accessible here: https://astre-apps.cirad.fr/apps/tracking-virus/. It showcases information from different surveillance components, displaying both surveillance data ("past" published datasets) and mock surveillance summary reports that were submitted through the WNIS ("current" datasets) with simulated WNV surveillance reports submitted in 2020–2021. The actors are currently testing several options and the system will evolve as new needs arise.

The VirusTracking application is divided into two main panels: the first panel is dedicated to option control (inputs) on the left, and the second panel on the right has graphical data reports (outputs) based on user preferences. Users may first select a disease (WNV) and the species under surveillance (human, equine, avian, wild birds, or mosquito surveillance or all the surveillance components at the same time). Users can then adjust the period and geographical location (i.e., by selecting/deselecting communes) of interest on which they want data to be presented. Data information is then shown and plotted dynamically on the right panel according to the input data user's selection. The resulting panel is organized as follows (**Figure 2A**):

- Overall statistics of reported tested and positive cases observed in the selected locations during the period.
- Histogram of the number of tests conducted chronologically,
- Histogram of positive cases reported chronologically,
- Guadeloupe region-centric geographical map showing the locations where individuals were sampled.
- Guadeloupe region-centric map reporting positive case vs. individuals tested ratio for each commune. These are represented as mini pie charts whose sizes are proportional to the number of tested cases.

Regarding chronology reports through histogram representation, bar width can be adjusted according to the accuracy required by the analysis, either daily, weekly, monthly, or even by year, to sum up, the information. In practice, this flexibility has

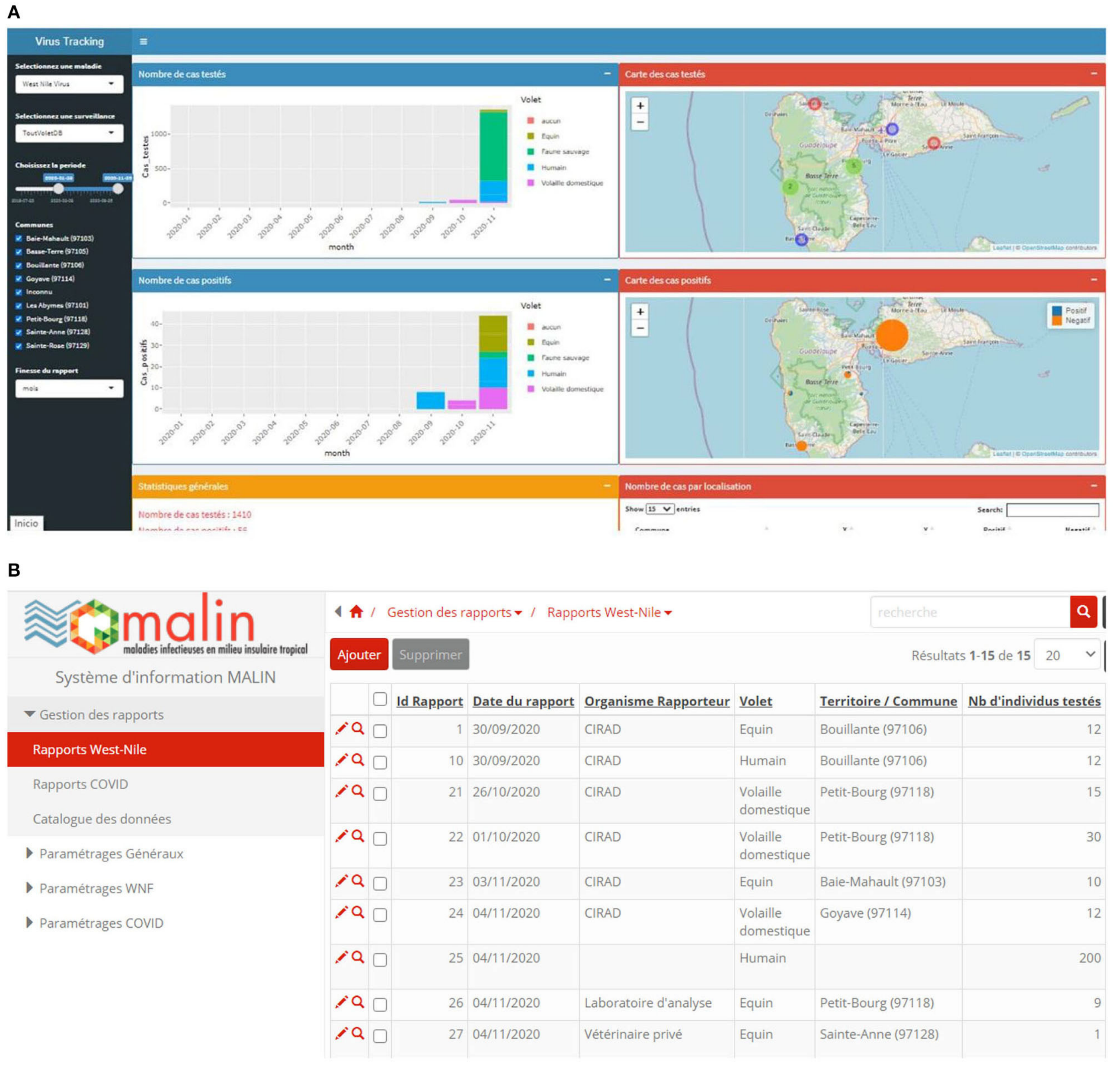

FIGURE 2 | (A) Screenshot of the VirusTracking West Nile Virus surveillance platform. The graphs show the reports submitted on the information system on eight communes of Guadeloupe (Baie-Mahault, Basse-Terre, Goyave, Les Abymes, Petit-Bourg, Sainte-Anne, Sainte-Rose) during 2020. The time unit is a month. The data are not real epidemiological data; they were the ones entered by the participants in the workshop for testing the tool. **(B)** Screenshot of the WNIS. WNV report section: The report ID with the organization that submitted the report is listed as well as the component under surveillance, commune, and number of tested and positive cases. The information and data do not correspond to actual data (participants entered them to test the platform).

been implemented because of the heterogeneous frequency of report acquisition.

The users can also gather information from different surveillance components at once, as different layers overlaid in the same histograms and geographical maps were added. This functionality may be of great importance for helping actors have an overview of the information. This functionality does not substitute Geographic Information Systems that would be helpful to understand WNV epidemiology in Guadeloupe.

Social Network Analysis

In total, sixteen (16) people out of 20 currently involved in WNV surveillance were interviewed. They were actors participating in all three components of the WNV surveillance (human, animal, and environmental) and belonged to the following institutions: CIRAD, IPG, SPF, CHU Pointe-à-Pitre, the French Agency for Biodiversity (OFB), the Regional Health Agency (ARS), the French Agency for Food, Environmental and Occupational Health & Safety (ANSES), Direction de

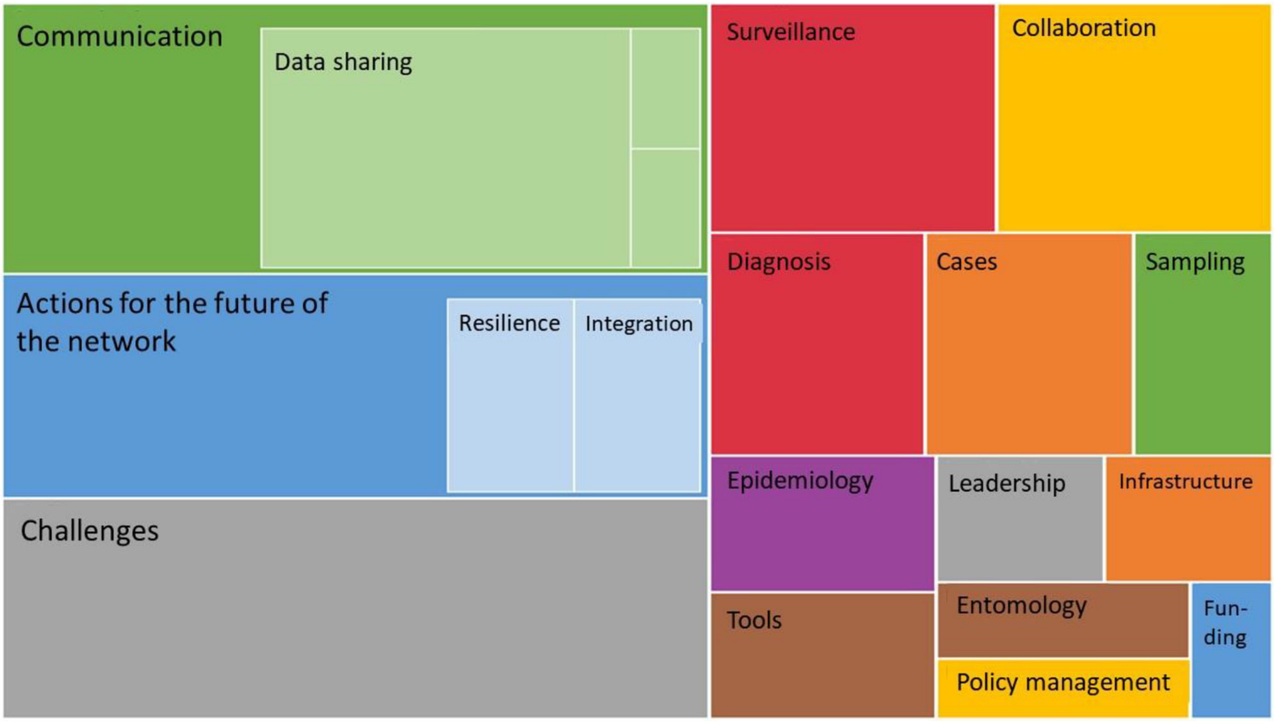

FIGURE 3 | Hierarchy chart of themes obtained from the SNA questionnaire using Nvivo software. The bigger the box, the more frequent the theme.

l'Alimentation, l'Agriculture et la Forêt Guadeloupe (DAAF Guadeloupe), and private veterinarians.

Actors talked about various themes, but their three main concerns addressed "communication," "current challenges," and the "actions for the future" of the network, as can be seen from **Figure 3**.

The network map of the surveillance system (**Figure 4**) is made up of 36 vertices and 88 edges, having a diameter of six (6), which is the minimum path length that can connect any pair of nodes in the network. The network reciprocity is 52%, meaning that among our pairs of nodes, half of them have a one-way exchange of information. Nearly three-quarters of the nodes (28, 77%) have less than five edges that connect them to other actors of the network. On the other hand, two nodes concentrate 22 and 31 edges (labeled NP and JP, respectively), meaning that more than half (53, 60.2%) of the connections are gathered around these two actors: the main hubs and authorities of information.

In addition to data information flows, actors and stakeholders also have provided suggestions and opinions about the levers and barriers of communication inside the system (**Table 2**), the main challenges (**Table 3**), and the priorities for improving the surveillance system (**Figure 5**).

Some actors indicated that their concerns had not been fully addressed and felt excluded from the network, albeit having particular tasks inside the surveillance system (data collection, laboratory diagnostics) and sometimes do not understand some procedures related to their components due to a lack of information and communication with other actors.

Actors from the human health component have expressed that their main concern is the absence of human cases or limited information available on the impact of WNV on the human population of Guadeloupe. Physicians are fully alert and appear not to be aware of the disease, and they do not have any specific instructions from public health authorities to prescribe WNV tests. Consequently, they do not prescribe WNV diagnostic tests, so possible mild WNF cases could be mistaken for dengue fever due to similar symptomatology and a high prevalence in the region. Also, not all laboratories can carry out WNV testing, so samples would be sent to overseas reference laboratories in France, which hampers the physicians' prescriptions and the centralization of the results by the local laboratories leading to a loss of information.

DISCUSSION

Constraints to Multidisciplinary and Cross-Sectoral Collaborations

These results show several limitations of the current WNV surveillance organization threatening the sustainability of the network. The SNA results show that flows of information between partners in Guadeloupe are constrained by the type of organization (or sector), a common practice where people communicate with those sharing the same working space or interests. WNV surveillance is mainly led by actors belonging to the animal health sector; they have created some links with

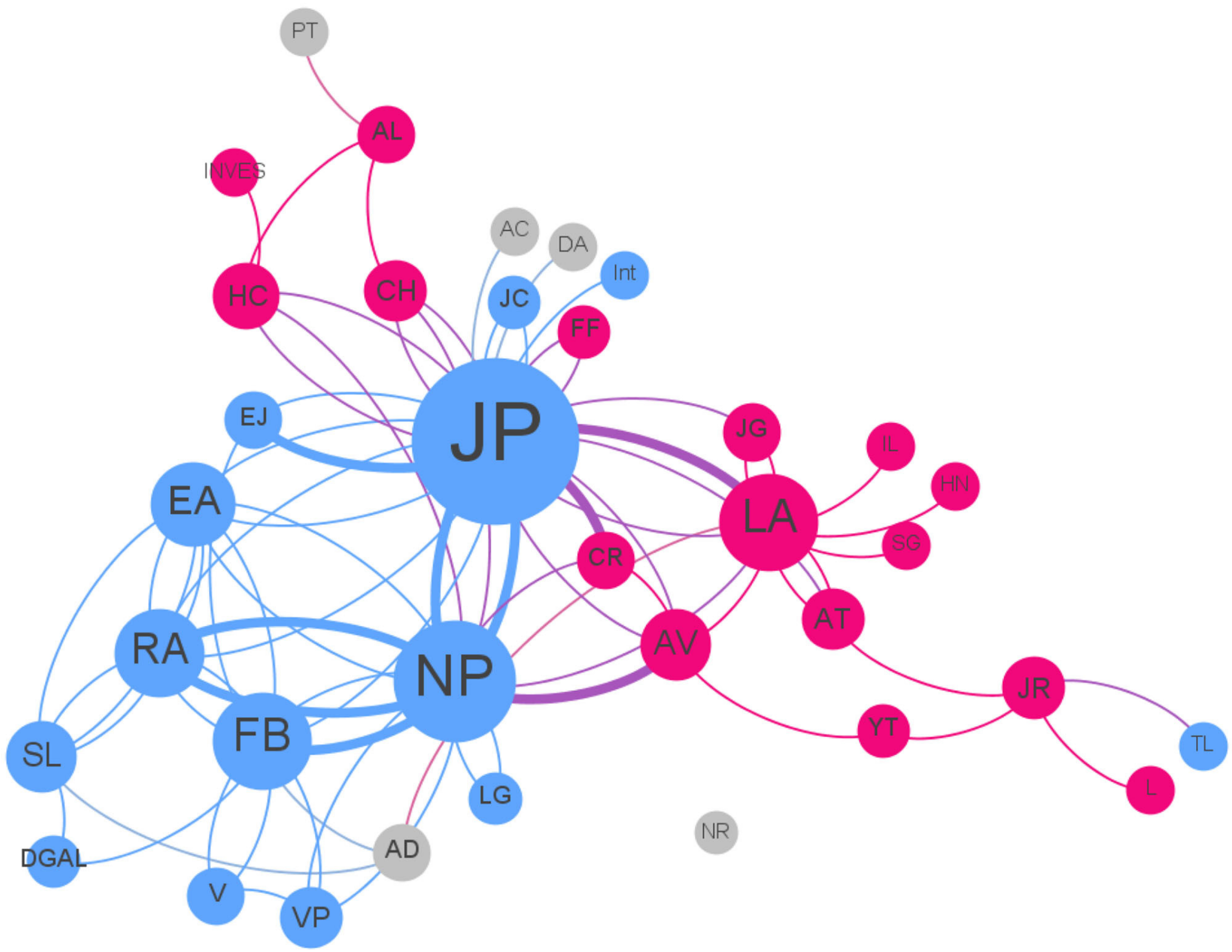

FIGURE 4 | Map of the West Nile Virus surveillance network in Guadeloupe. The colors represent the sectors the actors belong to: animal (Blue), human (Magenta), and the environment (Gray). Larger nodes have more edges. The thicker the lines, the more weight in the communication between two actors.

TABLE 2 | Constraints and levers for sharing data between actors.

Information sharing: levers and constraints	Actions recommended	Examples
What makes sharing WNV information easy?	• Partners know one another • Trust between partners • Relationships • Existence of available platforms for sharing information (meetings, seminars, newsletters, etc.) • Curiosity • Surveillance is divided, thus needs information from another actor to complete their own.	*"And another point, so I said yes, we know each other, we know what the others are doing, and we may have a common tool, um, possibly the Internet, finally the web, to share minimal information and alerts."*
What makes sharing WNV information difficult?	• WNV is not a health priority (lack of interest) in Guadeloupe • Information lacks detail • Lack of communication between organizations. • No tools to share information • Lack of cases (human health)	*"Because mainly I think it is not the priority of all people and organizations: they have their own priorities. They are not available for things like this."*

specific human health actors, which in turn are connected to isolated members inside their sector. The environmental component is also underrepresented and ought to be an essential addition to the WNV surveillance system in the future. SNA results also show the unevenness of the communication with: two members being the central actors having most connections and representing the link between actors—they act both as hubs and authorities—while most actors are a part of the system because they are linked to only one person inside the network. In these cases, it would be hard to recover the communication routes established by these actors if either node disappears. This organization results from the absence of a formal protocol and a lack of governance that encompasses all sectors, where roles, responsibilities, and communication mechanisms between each organization or actor would be described. Actors need to communicate and collaborate directly with one another. Getting to know other actors by setting up meetings or trust-building activities is vital to create long-lasting connections that can be reflected in professional work and the shaping of efficient working groups. The "beer-and-pizza concept" mentioned by professor Craig Stephen is quite efficient in forming stronger groups: actors are encouraged to meet in relaxed environments, thus building friendly relationships (33). In the south of France, annual meetings of the WNV surveillance in the early 2000s used to be organized in the heart of the Natural Regional Park of Camargue. They included a field trip, bird watching, and other activities, allowing actors from all sectors to meet and get to know each other in a preserved, unique environment, that was also the virus's playground. With the current COVID-19 pandemic, this might be a bigger challenge. However, there may be something innovative to do, bearing in mind that collaboration needs to be mainly understood as a human process and not an obligation inside the professional area. Furthermore, an organizational structure is desirable where actors can get to know one another, their work line, and possible contributions to the network. Trust and established relationships can make the difference in communication.

Anticipating the considerable limitation of information sharing in a context where partners are willing to share information, the WNIS, and R Shiny platform are expected to fill major gaps by providing supporting infrastructure to facilitate the exchange of information and knowledge between partners. Moreover, it is expected to facilitate integrated data analysis, the definition of new research and surveillance questions, and the coordination of future WNV surveillance and research

TABLE 3 | Main challenges of the WNV surveillance system with examples.

Main challenges of the WNV surveillance network	Quotes
No formal network and no existing protocols	*"There is no network. Individual activities are conducted independently from one another. There is no coordination. No established mechanisms for sharing information between the different actors…."*
Undetected transmission. Silent viral circulation	*"I think that with a disease, a flavivirus, you can have a lot of undetected transmissions. WN fever is not a disease that social security tells you to take a test for. That is why people have symptoms, but they are not systematically tested for WN."*
Proving viral circulation in humans (Human health problem)	*"And so we do not do tests, that's why we say there are no tests in humans, okay (...), but we don't look for them."*
No exchange of information between partners	*"We are not used to exchanging information or plan an integrated surveillance: I would say there are multiple activities and these activities are not connected, and there are a few exchanges of information from all the different sides."*
Early detection of the disease	*"I think the challenge is to be able to detect the reintroduction of the virus in our territories very quickly, and this detection is first of all through the animal surveillance system and mainly avian and equine."*
Lack of testing	*"If the clinician does not ask for WNV testing, it is impossible for the laboratory to add it systematically in every syndrome, neurologic syndrome."*

FIGURE 5 | Main actions that were recommended by actors to increase the resilience of the WNV surveillance system.

activities. If well-adopted, it may contribute to developing a systemic organization (polycentric, highly connected, and multidimensional), especially if it is extended to other vector-borne and zoonotic diseases.

With the advent of new information and communication technologies and their democratization over the last 10 years or so, IS have become more efficient and reliable: standardization of information, speed, reliability, availability, security, and shareability are all criteria for performance and optimization, which means that today IS are key tools in monitoring systems (39). However, it is essential to parallel an in-depth study of existing constraints (human resources in terms of skills, budgetary constraints, and technical constraints depending on the study site) so that the deployment of an IS based on new technologies thrives in the long-term.

Other than communication issues, concomitant participation in Gruel's study (47) on key attributes of "One Health" implementation highlights several other major weaknesses limiting the successful implementation of the "One Health" approach in the WNV surveillance network. There is a lack of formal "One Health" governance, coordination, and monitoring mechanisms. Moreover, there is no synergistic pooling of resources, no integrated data analysis, and a general lack of awareness of the "One Health" approach with an under-recognition of "One Health" professionals' roles. In addition, actors—mainly those from the public health sector—mentioned that WNV is not a priority and has fewer funding opportunities compared to other health threats like Leptospirosis, dengue, and currently Covid-19, which have a most significant public health impact in Guadeloupe.

Having a wider "One health" integrated surveillance network to establish collaborative programs to prevent and tackle diseases would probably be a good option, especially in a challenging environment like Guadeloupe where the turnover of persons in research/health agencies is frequent, the system is fragmented, and resources are scarce. Finally, Guadeloupe is distant from mainland France and communication between local and national epidemiological surveillance systems is inconsistent.

Implementation of a Pilot Integrated Surveillance in Guadeloupe

A strategy has been envisioned with the actors and recommendations were formulated during the final workshop to keep the WNV surveillance and research activities going on after this study, and shape the network on the longer term, linked at the national level, as overseas territories are generally poorly integrated.

WNV integrated surveillance in many European countries involved creating strong, well-integrated teams (36, 38, 48), which is still lacking in Guadeloupe. For this reason, the main short-term goal is to enhance collaboration and communication around the WNIS, the R shiny platform, and the use of partners' information to improve early warning systems for WNV based on sentinel animals. Big expectations have been set on these new technologies and are yet to be used regularly. An epidemiologist has been recruited for 1 year to moderate and facilitate communication within the network. She will operationalize the WNIS and conduct the integrated data analysis with the partners to increase WNV knowledge in Guadeloupe, posing new surveillance and research questions.

Specifically, integrated data analysis will allow identifying correlations between environmental variables and WNV circulation data in horses and poultry as well as with mosquito vector dynamics in Guadeloupe. Several environmental variables, including climatic factors, such as warmer temperatures at the beginning of the mosquito breeding season, landscape structures (comprising water bodies or higher normalized difference vegetation index), and reservoir bird ecology were shown to shape WNV circulation risks in different areas (49). These have been integrated into WNV models that analyze vector and host abundance spatially and more precisely map areas at-risk for WNV infections in Europe, the Mediterranean basin, and North America (50–52). Identifying such factors that are critical modulators for WNV circulation in Guadeloupe is a prerequisite for WNV risk modeling and mapping and anticipating future virus epizootics or epidemics.

Also, training workshops for partners on the use of the WNIS, databases, data visualization, and the surveillance system will be continued. Alongside, actors have identified four priority actions they will work on throughout 2021: (a) the governance and information sharing mechanisms, (b) surveillance protocols and links with the French Epidemiological Surveillance platform (ESA, https://www.plateforme-esa.fr/), (c) improvement of WNV and flavivirus diagnosis in humans in collaboration with the veterinary research diagnostic laboratory and the national reference laboratories for human and animal vector-borne diseases, and (d) databases and integrated data analysis, with the development of a consortium agreement.

Despite their little availability and constraints, all actors are eager to participate in the WNV surveillance amelioration with minor additional costs and want to collaborate and learn about what other actors have discovered regarding WNV, and that has not been published yet. In the future, the combined use of technology for disease surveillance and IS might give us a better idea of current disease circulation, providing strategies for the implementation of prevention and disease control programs in Guadeloupe (39). This integrated surveillance system could also be expanded to other mosquito-borne diseases or emerging zoonosis of concern.

It is also essential to address open questions about the presentation of WNF in humans in Guadeloupe. Public health experts with a background in neurology and diagnostics mentioned that the current sampling strategy is not adequate, and the lack of positive cases acts as a barrier for the detection of the pathogen in the human population. This is also related to a lack of disease awareness or WNV not being a priority for human health organizations. The budget for WNV surveillance is very limited and only intended to fund diagnostic assays. It is crucial to increase awareness of the existence of WNF in the region among clinicians to promote testing for the disease and gain epidemiological knowledge on the true burden of WNV in humans. Also, adding WNV testing to the prescription of patients that present dengue-like symptoms could help in identifying human WNV positive cases.

Currently, the environmental sector is not represented in the WNV surveillance network. Ecologists from the University of Antilles (UA), as well as several naturalist associations (ornithologists, bat specialists), are working with CIRAD and several institutes on a research project called, "Insula" (2020–2023), funded by the European Union and the Guadeloupe region. This project aims at studying the impact of biodiversity degradation of several ecosystems on the risks of transmission of vector-borne diseases in plants, animals, and humans. It was suggested to organize a collaboration between the WNV surveillance network and the Insula research project to organize mutually beneficial collaborations: pool some resources, organize joint activities, share relevant data/samples, etc. It is anticipated that this will help WNV surveillance get highly relevant data and information from wildlife and the environment until the French Office for Biodiversity in Guadeloupe starts its operations on wildlife disease surveillance.

Linking research and surveillance on emerging zoonotic diseases has always been considered essential both by research institutes and organizations in charge of public and animal health surveillance, however, it has historically been poorly operationalized. With the implementation of the "One Health" approach in Guadeloupe since 2019, the partners of the MALIN Project are pushing for a strong "One health" project aiming at strengthening research and surveillance of emerging health problems, including zoonotic/vector-borne diseases within the framework of the next European Research Development Funds (ERDF) program (2022–2027).

It would be interesting to include cycles of internal evaluations with feedback of the actors to adapt network operations to surveillance objectives and its governance regularly. In addition, evaluating the "one health-ness" of the WNV integrated surveillance in the near future would be important to see the degree of evolution of the operationality of the "One Health" approach. For this, several methodologies can be used to evaluate interventions like SNA and focused ethnography, as well as tools of the Network for the Evaluation of One Health (NEOH) (53) or the method proposed by Gruel et al. (47).

In the longer term, thanks to the collaborative efforts and future programs under development, we hope to enhance linkages with other French, EU, and global initiatives to prepare for pandemics and zoonosis prevention. Currently, the WNV surveillance in Guadeloupe is disconnected from the national level. Indeed, although the French Ministry of Agriculture and the French Ministry of Health are aware of the results of the WNV surveillance conducted in Guadeloupe in their respective animal and human population, other groups involved in the national WNV surveillance do not know much about WNV surveillance conducted in Guadeloupe and, more generally in other French overseas territories. Options to better integrate WNV information from Guadeloupe at the national level were discussed like establishing a formal communication between the WNV surveillance locally and the ESA platform "WNV group." Also, developing a surveillance protocol for the Wild bird component and defining the access to the "Epifaune" national database of the OFB monitoring wild bird mortality (https://ofb.gouv.fr/le-reseau-sagir) and mechanisms to inform the local WNIS need to be defined.

WNV is a pathogen that, even if silent in most Latin America and the Caribbean, is still circulating in the region, with strains continuously evolving in North America (11). It remains unclear if WNV strains are regularly introduced in Guadeloupe or if there is an episodic circulation of a local strain. In the case of WNV in Guadeloupe, many of the ecological cycle components have not been discovered yet, so the findings associated with the WNV surveillance in all components will be key to understand better the epidemiology of WNV in the Neotropics.

Also, a big concern within the "One Health" approach, in general, is a lack of experts in social, legal, and economic sciences (31). In the WNV surveillance system in Guadeloupe, not even one social scientist was mentioned or known to be a part of the system. Besides, the social sciences' expertise could be very useful in the future, providing insights into the population's needs and how the network can expand and communicate. When incorporating the human component, there is a strong connection between social and ecological factors that can make the difference in disease transmission and be taken into account while making prevention, control, or surveillance programs (54, 55). Involving actors belonging to non-profit or community organizations is vital because they are usually engaged in programs with the general population. Because of this interaction, they can act as key actors in creating programs that may impact health in the region (56). As well, links with policy-makers would be essential to make long-lasting changes in the health of Guadeloupe.

Finally, competencies outside the fields of science and health are an essential addition to "One Health" programs. Leadership and horizontal management are needed to manage a broad range of complex issues, to create and evaluate new partnerships and collaborations, and integrate the knowledge of various stakeholders. Solution finding techniques, flexibility, communication skills, team building, and trust development are capacities that anyone who works in a multidisciplinary environment needs to practice and develop (57). Often overlooked, those competencies will have to be considered in future projects—either through capacity building programs or recruitments—to sustain the collaborative efforts.

CONCLUSION

This work is one of the first collaborative works paving the way for subsequent "One Health" research and surveillance in Guadeloupe. It has started making improvements in communication and collaboration between actors of the WNV surveillance system, making actors aware of the existence of people that currently work in similar fields. With further improvements and changes to the network structure and organization, it might become a model of surveillance for other emerging zoonotic pathogens in Guadeloupe aiming to be resilient, which means able to respond to a crisis or adapt while keeping a strong and efficient communication. WNV circulation may be difficult to evidence in Guadeloupe, but actors need to be prepared for future threats of any type. Knowing one another and being already a part of a multidisciplinary team might reduce Guadeloupe's health vulnerability and make a difference in the course of a health emergency or an outbreak. Surveillance actors now have a tool to save time and money while building stronger relationships and inter-institutional cooperation along the way.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

JP designed, directed, coordinated, and organized all phases of the project. MG did the Social Network Analysis, interviews, and data collection from partners. DC and AD developed the information system and the R Shiny app. NP, LA, AV-R, and CH-S provided surveillance information and input from their sectors during the participatory workshops. MG and JP drafted the article. SL participated actively in the latest workshops. All authors contributed to the article, discussed results, participated in the workshops and meetings, and approved the submitted version.

FUNDING

This work was a part of the MALIN project funded by the European Union on the Guadeloupe Region under the European Research and Development Funds (ERDF) 2014-2020 program (Grant 2018-FED-1084).

ACKNOWLEDGMENTS

The authors wish to acknowledge all the actors of the WNV surveillance network who were interviewed: Evva Jolt, Jan Cherdieu (veterinarians), Annie Lanuzel and Hugo Chaumont (CHU), Anouk Decors, Ronyl Narfez, Stéphanie Desveaux and Antonny Grolleau (OFB), Cedric Ramdini (ARS) and Jacques Rosine (Santé Publique France), and Fabienne Barthelemy and Aurelie de San Mateo (DAAF). The authors wish to acknowledge Sylvain Falala (INRAE) and Guillaume Cornu (CIRAD) for their support with R Shiny and Craig Stephen. The work has been undertaken as part of the One Health Leadership capacity building program implemented in Guadeloupe within the Malin project framework. MG benefited from the European Commission through the Erasmus + programs and the Infectious Disease and One Health Master.

REFERENCES

1. Reisen WK. Ecology of West Nile virus in North America. *Viruses.* (2013) 5:2079–105. doi: 10.3390/v5092079
2. Ciota AT. West Nile virus and its vectors. *Curr Opin Insect Sci.* (2017) 22:28–36. doi: 10.1016/j.cois.2017.05.002
3. Campbell GL, Marfin AA, Lanciotti RS, Gubler DJ, Nile W. West Nile virus. *Lancet Infect Dis.* (2002) 2:519–29. doi: 10.1016/S1473-3099(02)00368-7
4. Maclachlan NJ, Dubovi E. Flaviviridae. In: Maclachlan NJ, Dubovi E, editors. *Fenner's Veterinary Virology* (Burlington, MA: Academic Press). p. 525–45.
5. Gray TJ, Webb CE. A review of the epidemiological and clinical aspects of West Nile virus. *Int J Gen Med.* (2014) 7:193–203. doi: 10.2147/IJGM.S59902
6. Barros SC, Ramos F, Fagulha T, Duarte M, Henriques AM, Waap H, et al. West Nile virus in horses during the summer and autumn seasons of 2015 and 2016, Portugal. *Vet Microbiol.* (2017) 212:75–9. doi: 10.1016/j.vetmic.2017.11.008
7. OIE. West Nile fever. In: *Manual of Diagnostic Tests and Vaccines for Terrestrial Animals* (Paris: OIE). p. 1–14.
8. Hubálek Z, Halouzka J. West Nile fever — a reemerging mosquito-borne viral disease in Europe. *Emerg Infect Dis.* (1999) 5:643–50. doi: 10.3201/eid0505.990505
9. Rappole JH, Derrickson SR, Hubálek Z. Migratory birds and spread of West Nile. *Emerg Infect Dis.* (2000) 6:319–28. doi: 10.3201/eid0604.000401
10. Kramer LD, Ciota AT, Kilpatrick AM. Introduction, spread, and establishment of West Nile virus in the Americas. *J Med Entomol.* (2019) 56:1448–55. doi: 10.1093/jme/tjz151
11. Hadfield J, Brito AF, Swetnam DM, Vogels CBF, Tokarz RE, Andersen KG, et al. Twenty years of West Nile virus spread and evolution in the Americas visualized by Nextstrain. *PLoS Pathog.* (2019) 15:e1008042. doi: 10.1371/journal.ppat.1008042
12. Dupuis AP, Marra PP, Kramer LD. Serologic evidence of West Nile virus transmission, Jamaica, West Indies. *Emerg Infect Dis.* (2003) 9:860–3. doi: 10.3201/eid0907.030249
13. Quirin R, Salas M, Zientara S, Zeller H, Labie J, Murri S, et al. West Nile virus, Guadeloupe. *Emerg Infect Dis.* (2004) 10:706–8. doi: 10.3201/eid1004.030465
14. Komar N, Clark GG. West Nile virus activity in Latin America and the Caribbean. *Rev Panam Salud Publica.* (2006) 19:112–7. doi: 10.1590/S1020-49892006000200006
15. Dupuis AP, Marra PP, Reitsma R, Jones MJ, Louie KL, Kramer LD. Short report: Serologic evidence for West Nile virus transmission in Puerto Rico and Cuba. *Am J Trop Med Hyg.* (2005) 73:474–6. doi: 10.4269/ajtmh.2005.73.474
16. Anthony SJ, Garner MM, Palminteri L, Navarrete-Macias I, Sanchez-Leon MD, Briese T, et al. West Nile virus in the British Virgin Islands. *Ecohealth.* (2014) 11:255–7. doi: 10.1007/s10393-014-0910-6
17. Bolfa P, Jeon I, Loftis A, Leslie T, Marchi S, Sithole F, et al. Detection of West Nile Virus and other common equine viruses in three locations from the Leeward Islands, West Indies. *Acta Trop.* (2017) 174:24–8. doi: 10.1016/j.actatropica.2017.06.023
18. Lefrançois T, Blitvich BJ, Pradel J, Molia S, Vachiéry N, Pallavicini G, et al. West Nile virus Surveillance, Guadeloupe, 2003-2004. *Emerg Infect Dis.* (2005) 11:1100–3. doi: 10.3201/eid1107.050105
19. Reiter P. Weather, vector biology and arboviral recrudescence. In: Monath TP, editor. *The Arboviruses: Epidemiology and Ecology*. Boca Raton, FL: CRC Press.
20. Wiese D, Escalante AA, Murphy H, Henry KA, Gutierrez-Velez VH. Integrating environmental and neighborhood factors in MaxEnt modeling to predict species distributions: a case study of Aedes albopictus in southeastern Pennsylvania. *PLoS ONE.* (2019) 14:e0223821. doi: 10.1371/journal.pone.0223821
21. Kilpatrick AM. Globalization, land use, and the invasion of West Nile virus. *Science.* (2011) 334:323–7. doi: 10.1126/science.1201010

22. Cornevin R. *Guadeloupe*. Encyclopædia Britannica (2018). Available online at: https://www.britannica.com/place/Guadeloupe (accessed July 20, 2020).
23. Pradel J, Chalvet Monfray K, Molia S, Vachiéry N, Rousteau A, Imbert D, et al. Risk factors for West Nile virus seropositivity of equids in Guadeloupe. *Prev Vet Med.* (2009) 92:71–8. doi: 10.1016/j.prevetmed.2009.07.001
24. Office Nationale des Forets. *L'etat de la biodiversité en Guadeloupe*. Available online at: http://www1.onf.fr/guadeloupe/$++$oid$++$640/@@display_advise.html (accessed July 20, 2020).
25. Pages N, Vachiery N, Lefrançois T, Albina E, Giraud-Girard K, Pradel J. West Nile virus surveillance in Guadeloupe, French West Indies. In: Chueca M, Alten Bulent MA, editors. *International SOVE Congress. New Technology Conquering Old Vectors?* Palma de Mallorca, Spain (2017). p. 84.
26. Schaffner F. *Les moustiques de Guadeloupe (Diptera, Culicidae)*. Parc Nationale de la Guadeloupe EID Méditerranée (2003).
27. Levesque A, Jaffard M-E. Fifteen new bird species in guadeloupe (f.w.i.). *El Pitirre.* (2001) 15:5–6.
28. Pages N, Vachiery N, Lefrançois T, Giraud-girard K, Albina E, Pradel J. West-Nile in the Caribbean. In: *Xth International Congress for Veterinary Virology*. Montpellier, France.
29. Agence francaise de securité Sanitaire des aliments. *Rapport sur la surveillance de l'infection à virus West Nile en France*. Maisons-Alfort (2004).
30. Chaumont H, Roze E, Tressières B, Lazarini F, Lannuzel A. Central nervous system infections in a tropical area: influence of emerging and rare infections. *Eur J Neurol.* (2020) 27:2242–9. doi: 10.1111/ene.14422
31. Lerner H, Berg C. A comparison of three holistic approaches to health: One Health, EcoHealth, and Planetary Health. *Front Vet Sci.* (2017) 4:163. doi: 10.3389/fvets.2017.00163
32. Stephen C, Karesh WB. Introduction is One Health delivering results? *Rev sci Tech Off Int Epiz.* (2014) 33:375–9. doi: 10.20506/rst.33.2.2301
33. Stärk KDC, Arroyo Kuribreña M, Dauphin G, Vokaty S, Ward MP, Wieland B, et al. One Health surveillance - more than a buzz word? *Prev Vet Med.* (2015) 120:124–30. doi: 10.1016/j.prevetmed.2015.01.019
34. Braks M, Medlock JM, Hubalek Z, Hjertqvist M, Perrin Y, Lancelot R, et al. Vector-borne disease intelligence: strategies to deal with disease burden and threats. *Front Public Heal.* (2014) 2:280. doi: 10.3389/fpubh.2014.00280
35. Amato L, Dente MG, Calistri P, Declich S. Integrated early warning surveillance: achilles′ heel of one health? *Microorganisms.* (2020) 8:1–10. doi: 10.3390/microorganisms8010084
36. Chaintoutis SC, Dovas CI, Papanastassopoulou M, Gewehr S, Danis K, Beck C, et al. Evaluation of a West Nile virus surveillance and early warning system in Greece, based on domestic pigeons. *Comp Immunol Microbiol Infect Dis.* (2014) 37:131–41. doi: 10.1016/j.cimid.2014.01.004
37. Paternoster G, Tomassone L, Tamba M, Chiari M, Lavazza A, Piazzi M, et al. The degree of One Health implementation in the West Nile virus integrated surveillance in Northern Italy, 2016. *Front Public Heal.* (2017) 5:236. doi: 10.3389/fpubh.2017.00236
38. Vidanović D, Barbić L, Jeličić P, Lazić S, Radmanić L, Lupulović D, et al. Importance of multidisciplinary and regional collaboration in integrated West Nile virus surveillance - the "One Health" concept. *Infektološki Glas.* (2020) 39:40–7. doi: 10.37797/ig.39.2.2
39. Chavernac D, Hendrikx P, LeBel S, Lancelot R. Les nouvelles technologies de l'information appliquées à la vigilance en santé animale. In: *Bull épidémiologique, santé Anim Aliment.* (2015). p. 51–4.
40. Hillmann D. *Guía de uso del Dublin Core.* (2003). p. 1–9. Available online at: https://www.dublincore.org/specifications/dublin-core/usageguide/ (accessed November 2020).
41. van Duijn MAJ, Vermunt JK. What is special about social network analysis? *Methodol Eur J Res Methods Behav Soc Sci.* (2006) 2:2–6. doi: 10.1027/1614-2241.2.1.2
42. Blanchet K, James P. How to do (or not to do). a social network analysis in health systems research. *Health Policy Plan.* (2012) 27:438–46. doi: 10.1093/heapol/czr055
43. Crossley N, Bellotti E, Edwards G, Everett MG, Koskinen J, Tranmer M. *Social Network Analysis for Ego-Nets.* London: SAGE (2015).
44. Bikker AP, Atherton H, Brant H, Porqueddu T, Campbell JL, Gibson A, et al. Conducting a team-based multi-sited focused ethnography in primary care. *BMC Med Res Methodol.* (2017) 17:1–9. doi: 10.1186/s12874-017-0422-5
45. Rashid M, Hodgson CS, Luig T. Ten tips for conducting focused ethnography in medical education research. *Med Educ Online.* (2019) 24:1–7. doi: 10.1080/10872981.2019.1624133
46. Bastian M, Heymann S, Jacomy M. Gephi: an open source software for exploring and manipulating networks. In: *BT - International AAAI Conference on Weblogs and Social. Int AAAI Conf Weblogs Soc Media.* (2009) p. 361–2.
47. Rüegg SR, Buttigieg SC, Goutard FL, Binot A, Morand S, Thys S. Concepts and experiences in framing, integration and evaluation of One Health and EcoHealth. *Front. Vet. Sci.* (2019) 6:155. doi: 10.3389/fvets.2019.00155
48. Gossner CM, Marrama L, Carson M, Allerberger F, Calistri P, Dilaveris D, et al. West nile virus surveillance in europe: moving towards an integrated animal-human-vector approach. *Eurosurveillance.* (2017) 22:1–10. doi: 10.2807/1560-7917.ES.2017.22.18.30526
49. Marini G, Manica M, Delucchi L, Pugliese A, Rosà R. Spring temperature shapes West Nile virus transmission in Europe. *Acta Trop.* (2021) 215:105796. doi: 10.1016/j.actatropica.2020.105796
50. Chevalier V, Tran A, Durand B. Predictive modeling of West Nile virus transmission risk in the mediterranean basin: how far from landing? *Int J Environ Res Public Health.* (2013) 11:67–90. doi: 10.3390/ijerph110100067
51. Hess A, Davis JK, Wimberly MC. Identifying environmental risk factors and mapping the distribution of West Nile virus in an endemic region of North America. *GeoHealth.* (2018) 2:395–409. doi: 10.1029/2018GH000161
52. Durand B, Tran A, Balança G, Chevalier V. Geographic variations of the bird-borne structural risk of West Nile virus circulation in Europe. *PLoS ONE.* (2017) 12:e0185962. doi: 10.1371/journal.pone.0185962
53. Rüegg SR, Buttigieg SC, Goutard FL, Binot A, Morand S, Thys S, et al. *Editorial: Concepts and Experiences in Framing, Integration and Evaluation of one Health and Ecohealth* (2019).
54. Woldehanna S, Zimicki S. An expanded One Health model: integrating social science and One Health to inform study of the human-animal interface. *Soc Sci Med.* (2015) 129:87–95. doi: 10.1016/j.socscimed.2014.10.059
55. Destoumieux-Garzón D, Mavingui P, Boetsch G, Boissier J, Darriet F, Duboz P, et al. The one health concept: 10 years old and a long road ahead. *Front Vet Sci.* (2018) 5:1–13. doi: 10.3389/fvets.2018.00014
56. Schoch-spana M, Franco C, Nuzzo JB, Usenza C. Community engagment: leadership tool for catastrophic health events. *Biosecur Bioterror Biodefen Strateg Pract Sci.* (2007) 5:8–25. doi: 10.1089/bsp.2006.0036
57. Stephen C, Stemshorn B. Leadership, governance and partnerships are essential One Health competencies. *One Heal.* (2016) 2:161–3. doi: 10.1016/j.onehlt.2016.10.002

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Public Health

HYPOTHESIS AND THEORY
published: 10 June 2021
doi: 10.3389/fpubh.2021.637897

From Modern Planetary Health to Decolonial Promotion of One Health of Peripheries

Oswaldo Santos Baquero[1,2]*, *Mario Nestor Benavidez Fernández*[3] and *Myriam Acero Aguilar*[4]

[1] Department of Preventive Veterinary Medicine and Animal Health, School of Veterinary Medicine and Animal Science, University of São Paulo, São Paulo, Brazil, [2] nPeriferias – Research Group on Peripheries, Institute of Advanced Studies, University of São Paulo, São Paulo, Brazil, [3] Facultad de Humanidades y Ciencias de la Educación, Universidad de San Buenaventura, Bogotá, Colombia, [4] Departamento de Salud Animal, Grupo de Investigación en Estudios Humano Animal, Facultad de Medicina Veterinaria y de Zootecnia, Universidad Nacional de Colombia, Bogotá, Colombia

OPEN ACCESS

Edited by:
Christina Pettan-Brewer, University of Washington, United States

Reviewed by:
Serge Morand, Centre National de la Recherche Scientifique (CNRS), France
Jennika Virhia, University of Glasgow, United Kingdom

***Correspondence:**
Oswaldo Santos Baquero
baquero@usp.br

Specialty section:
This article was submitted to Planetary Health, a section of the journal Frontiers in Public Health

Received: 04 December 2020
Accepted: 10 May 2021
Published: 10 June 2021

Citation:
Baquero OS, Benavidez Fernández MN and Acero Aguilar M (2021) From Modern Planetary Health to Decolonial Promotion of One Health of Peripheries. Front. Public Health 9:637897. doi: 10.3389/fpubh.2021.637897

The concept of Planetary Health has recently emerged in the global North as a concern with the global effects of degraded natural systems on human health. It calls for urgent and transformative actions. However, the problem and the call to solve it are far from new. Planetary health is a colonial approach that disregards alternative knowledge that over millennia have accumulated experiences of sustainable and holistic lifestyles. It reinforces the monolog of modernity without realizing that threats to "planetary health" reside precisely in its very approach. It insists on imposing its recipes on political, epistemological, and ontological peripheries created and maintained through coloniality. The Latin American decolonial turn has a long tradition in what could be called a "transformative action," going beyond political and economic crises to face a more fundamental crisis of civilization. It deconstructs, with other decolonial movements, the fallacy of a dual world in which the global North produces epistemologies, while the rest only benefit from and apply those epistemologies. One Health of Peripheries is a field of praxis in which the health of multispecies collectives and the environment they comprise is experienced, understood, and transformed within symbolic and geographic peripheries, ensuing from marginalizing apparatuses. In the present article, we show how the decolonial promotion of One Health of Peripheries contributes to think and advance decentralized and plural practices to attend to glocal realities. We propose seven actions for such promotion.

Keywords: One Health of Peripheries, modernity, coloniality, decolonial turn, health inequities, One Health, Planetary Health, more-than-human biopolitics

INTRODUCTION

Modernity is a popular concept, often referred to the idea of progress, to positive and necessary changes to build a better future. Less famous is the critical comprehension of the modernity/coloniality cultural complex. This is not fortuitous; modernity is a narrative built by Western civilization to highlight its achievements (rationality, science, and technology) and conceal its dark side (genocide, expropriation, forced displacement, and exploitation) (1–3).

This dark side of modernity is coloniality; it is "the underlying logic of the foundation and unfolding of Western civilization from Renaissance to today of which historical colonialisms have been a constituent, although, downlpayed dimension" (3). Colonialism designates the political, social, and cultural domination in territories occupied by Europeans, typical of the period of colonization of America, which, far from being the discovery of America, was what Dussel called the discovery of an invasion and framed as the very origin of modernity (4).

The global South is a metaphor regarding the "field of epistemic challenges that seek to repair the damage and historical impacts caused by capitalism in its colonial relationship with the world" [translation is ours] (5). Therefore, the global South also includes Northern places. With the epistemologies of the South, the critiques of modernity cease to be exclusively internal (from the global North), making the colonial aspects of modern rhetoric evident (6). The epistemologies of the South show us that beyond economic crises, dictatorships, and corrupt governments, we are experiencing a crisis of civilization of more than five centuries (7), with devastating effects on health.

In Latin America, philanthropic support has helped to mitigate some of the health effects of the crisis of civilization, transferring small fractions of the wealth of a few rich philanthrocapitalists to the poorest, without affecting the consumption and accumulation patterns of the former, and enabling major transformations in the material conditions of the latter. This has made it possible to legitimize the elites and avoid responsibility for the poverty they generate and the exploitation that underpins the growth of their wealth. The Rockefeller Foundation's philanthrocapitalism has been around since the early 20th century, with strategies to shape the health professions and structure public health services (8–10).

But such strategies have also generated decolonial health responses. This is the case of Collective Health (9, 11), Critical Epidemiology (12), and South-South International Health (13). However, these responses inherited part of the colonial anthropocentrism and have treated health as a predominantly human phenomenon. Other beings appear only as vectors, reservoirs, or determinants of human health. Notwithstanding, it is worth highlighting the progress of the Ecuadorian school in its debates on the social determination of animal health (14) and animal production management (15).

In the report of The Rockefeller Foundation–Lancet Commission on Planetary Health, non-human beings appear within terrestrial systems that only have instrumental value, due to their role in human health (16). However, animal health takes prominence in One Health, another approach fostered by the Foundation. One Health refers to the human-animal-environmental health interface and has gained popularity for its convenience to address pandemics, emerging diseases, and antimicrobial resistance.

Like previous projects of the Foundation, Planetary Health and One Health can be read as proposals for preserving the capitalist order in the face of the perceived need for social change. More specifically, these two approaches pursue the prevention and control of environmental deterioration and animal diseases that impact human health, to avoid more instability in the capitalist order. As might be expected, the colonial aspects of these proposals have not been unnoticed (17–19), and in this paper, we will contribute by further exploring those aspects.

One Health of Peripheries is a decolonial response to experience, understand, and improve the well-being of marginalized multispecies collectives (20). Baquero presents the biopolitics, social *determination*, and field of praxis of One Health of the Peripheries, highlighting the symbolic character of the peripheries and leaving implicit its decolonial foundation (20). One of the features that shows this foundation is the opposition to animalization, a marginalizing apparatus registering non-human animals and marginalized human groups in colonial domination spaces that determine epidemiological profiles.

The excess risks underlying peripheral epidemiological profiles increase the relevance of primary, secondary, and tertiary prevention, that is, of measures directed at specific factors to (1) avoid, (2) early detect and treat, and (3) mitigate the effects of diseases or ill-health. However, the preventive approach is limited to a negative ontology of health, to the absence of diseases or ill-health. On the other hand, health promotion works on a positive ontology, regarding health as a resource and capability to live well. Despite the overlap between prevention and promotion, as the first subsumes the second (environmental sanitation prevents diseases and not having diseases increases the resources and capabilities to live well), the absence of diseases or ill-health is not enough in terms of promotion because that absence does not exhaust the possibility of a better life. Promotion is not restricted to risk factors or specific problems; it also works on resources and capabilities.

One Health of Peripheries is inherently preventive because its field of praxis generates excess risk and disease burden. However, peripheries are more than collections of risks and injuries; they have structurally oppressed resources and capabilities, which the ecology of knowledge can release in a multispecies health framework. Such release is the task of decolonial promotion of One Health of Peripheries.

In what follows, we present the myth of modernity and then continue with the colonial precedents of the Rockefeller Foundation's philanthropy and the coloniality in the report of The Rockefeller Foundation–Lancet Commission on Planetary Health. After this decolonial turn, we move to the ecology of knowledge to frame our proposal of decolonial promotion of One Health of Peripheries. This paper is a continuation of another one dedicated to introducing One Health of Peripheries (20).

MODERNITY AND COLONIALITY

Modernity designates a political, social, and cultural European process that in the 15th century allowed the emergence of capitalism, and since then, its development as a global economic system (21). Modernity has as a backdrop the idea of unlimited progress. Economic and social changes promoted by scientific and technological development promised the construction of a better future (22). The Eurocentric and colonial character of modernity has been questioned, particularly by the Latin

American decolonial turn (23–25). Dussel pointed out two connotations of modernity: one, primary and positive, that understands modernity as an effort of rational emancipation that opens for humanity a new historical development, and the other, secondary and negative, in which modernity justifies irrational violence (26). According to this perspective, the only civilizing possibility for the "barbarian" peoples seems to be their gradual incorporation into the modern and Eurocentric project that depends to a large extent on the epistemological authority and alleged ontological superiority (racial, ethnic, geopolitical) of the global North (2). The incorporation to that project (modernization) has not been, however, an encounter between equals, but on the contrary, a violent conversion.

This violence, invested with heroism and redemption, marks the myth of modernity, synthesized by Dussel in seven elements: '(1) Modern (European) civilization understands itself as the most developed, the superior, civilization. (2) This sense of superiority obliges it, in the form of a categorical imperative, as it were, to "develop" (civilize, uplift, educate) the more primitive, barbarous, underdeveloped civilizations. (3) The path of such development should be that followed by Europe in its own development out of antiquity and the Middle Ages. (4) Where the barbarian or the primitive opposes the civilizing process, the praxis of modernity must, in the last instance, have recourse to the violence necessary to remove the obstacles to modernization. (5) This violence, which produces, in many different ways, victims, takes on an almost ritualistic character: the civilizing hero invests his victims (the colonized, the slave, the woman, the ecological destruction of the earth, etc.) with the character of being participants in a process of redemptive sacrifice. (6) From the point of view of modernity, the barbarian or primitive is in a state of guilt (for, among other things, opposing the civilizing process). This allows modernity to present itself not only as innocent but also as a force that will emancipate or redeem its victims from their guilt. (7) Given this "civilizing" and redemptive character of modernity, the suffering and sacrifices (the costs) of modernization imposed on "immature" peoples, enslaved races, the "weaker" sex, etcetera, are inevitable and necessary' (1).

Such suffering and sacrifice become less visible in the light of the seduction that turns modernity into aspiration, rather than imposing it through systematic and constant repression: 'colonizers also imposed a mystified image of their own patterns of producing knowledge and meaning. At first, they placed these patterns far out of reach of the dominated. Later, they taught them in a partial and selective way, in order to co-opt some of the dominated into their own power institutions. Then European culture was made seductive: it gave access to power. After all, beyond repression, the main instrument of all power is its seduction. Cultural Europeanisation was transformed into an aspiration. It was a way of participating and later to reach the same material benefits and the same power as the Europeans: viz, to conquer nature in short for "development." European culture became a universal cultural model' (2). But not everyone attains the aspiration. The ontological superiority of the myth of modernity limits material benefits and the exercise of power so that racial, ethnic, and geocultural attributes frustrate or advance the aspiration, depending on their configuration (27).

The configurations of these attributes define the place of hegemonic production of epistemologies of health and, what is more important, how they materialize in health. Within modernity, the global North produces epistemologies. In contrast, the global South is limited to benefit from the transfer of knowledge or knowledge building within the epistemological production patterns established by modernity. As we will see, the global North's health discourses align with the interests of the dominant groups of dominant nations, and to the extent that they neglect the interests of peripheral groups, they induce particular epidemiological profiles.

COLONIAL PRECEDENTS OF THE ROCKEFELLER FOUNDATION

Capitalism, made possible by coloniality, generates figures like the one recently reported by Coffey and collaborators (28): in 2019, the world's billionaires, just 2,153 people, accumulated more wealth than 4.6 billion people. In other words, in a world population of 7.7 billion, the wealth concentrated by 0.000028% of the population was greater than that of 59.7%. In light of the so-called Law of diminishing marginal utility, figures like that make possible the transfer of small fractions of wealth from the wealthiest to the poorest without affecting the former's consumption and accumulation patterns while enabling major transformations in the material conditions of the latter. On the one hand, we can see these transformations as philanthropic successes. On the other hand, as a strategy to legitimize the elites and avoid responsibility for the poverty they generate and the exploitation that underpins the growth of their wealth. The dialectics between both sides reproduces inequalities and determine conditions of possibility to produce alternatives.

The mentioned transfers can increase the symbolic and cultural capital of elites and consequently their economic capital. Moreover, legitimization strategies are also economic investments. Among the main strategies is the influence on the educational system to favor the reproduction of the dominant classes by forming profiles to occupy high positions in the state bureaucracy and the field of power (9). It was not by chance that in the early 20th century, the United States' industrialization allowed the accumulation of great fortunes and the establishment of influential universities (today leading prestigious global rankings according to modern criteria), many of which are partially homonyms with their founders' magnates (29). John D. Rockefeller, the first world billionaire and owner of the Standard Oil Company, contributed to founding the University of Chicago (29).

According to Vieria-da-Silva (9), philanthropists at the beginning of the 20th century anticipated a social reform that they saw as inevitable, investing in scientific approaches to social issues that did not threaten the capitalist order. The Rockefeller Sanitary Commission was created in 1909 (The Rockefeller Institute in 1901 and The Rockefeller Foundation in 1913). One of its central objectives was the industrialization of the agrarian South and its articulation to the capitalist interests of the North (9).

The Rockefeller Foundation continued to invest and intervene in the research and development of medicine (9). In 1947, its official Fred Sopper became director of the Opas, an institution subordinated to the United States' health policies and officially directed from that country until 1958 (9). Only after the Second War, with the creation of the WHO, the Opas became a Regional Office of that organization. During the Cold War, the United States' foreign policy, in defense of free trade and foreign investment, involved the creation of a favorable image (9). According to Tota, Nelson Rockefeller, Coordinator of the Office of the Coordinator of the Inter-Americans Affairs, contributed to an explicit project to promote the United States' image (30).

In the dispute over the monopoly of legitimate healthcare practices in Latin America, the Rockefeller Foundation's goal was to replace the French model (9). In the 1950's, the Opas was fundamental to this objective, through its strategies to spread Preventive Medicine, an ideological movement to protect the interests of Private Medicine, in the face of two problems: the increasing cost of Medical Care in the United States and the possibility of a State intervention (8). These problems already worried the American Associations of medical colleges, as Arouca showed (8) by citing Fishbein and Bierring (31): "There is a special need that the medical profession develops some method by which the greatest possibilities of modern medicine in the way of diagnosis, treatment and prevention of diseases, may be brought within the reach of all people. This function, it is *believed, should be performed by the medical profession and not to any form of State Medicine*" [the original citation is entirely emphasized].

COLONIALITY IN THE REPORT OF THE ROCKEFELLER FOUNDATION–LANCET COMMISSION ON PLANETARY HEALTH

The report of the Rockefeller Foundation-Lancet Commission on Planetary Health maintains the Foundation's historical concern with inequality, the health of the poorest, and the environment. Such insistence is again a colonial proposal for preserving the capitalist order in the face of the perceived need to avoid environmental deterioration and its impacts on human health.

Although we discussed some Rockefeller Foundation's colonial precedents in the previous section, it is worth noting that Planetary Health also has precedents omitted in the report (19). Over the last half-century, integrative medicine, holistic medicine, and many scholars have talked about the need for a healthy planet, even using the expression "planetary health" (19). So in what follows, we continue previous contributions that look beyond the *ahistorical* and colonial perspective of the Rockefeller Foundation-Lancet Commission report (19, 32, 33).

In a typically colonial attitude, the report ignores an enormous diversity of worldviews that do not separate humans from nature or think that degrading nature does not affect human health and well-being. Worldviews with millenary legacies in which it is not new to think that health and well-being are also nature: "The importance of the natural environment in supporting human health and well-being *is only becoming clear* as the Earth's systems are degraded" [emphasis is ours] (16).

How is the modern trajectory of humanity progressing if there have never been so many victims of genocide, dispossession, forced displacement, and exploitation? Which humanity is the one that progresses? The same colonizing and modern humanity for which there is only one civilization, even though Western civilization is known to coexist with other civilizations: "Put simply, planetary health is the health of human civilization and the state of the natural systems on which it depends" (16).

It is not the humanity of backward and irrational peoples with visionary healers. It is rational humanity with visionaries from the global North: "[...] Tony McMichael whose visionary book Planetary Overload, published more than 20 years ago, presciently addressed many of the issues that confront the world at present" (16).

The previous decolonial reading of the report does not imply its total rejection. The problems pointed out by the Commission must be solved, and it is pertinent to evaluate the attempts at resolution, for which, as the Commission indicates, quantitative indicators are helpful. But these should be used considering their different implications.

Let's look at two examples from the report. Between 1990 and 2012, the percentage of stunted children decreased from 50 to 30%, a significant advance in relative terms. However, in absolute terms, this reduction represented an increase of 14 million children, a number only exceeded by the total population of 7 European Union member states in 2011. Overall, there were 58 million children—predominantly from the global South—stunted in 2012, a number surpassed only by the population size of 4 European Union member states in 2011. Thus, in its absolute and relative version, a numerical indicator tells different stories that must be considered in a critical and integrated way. In the global South, it is no progress to have millions of additional stunted children, while wealth concentration in the global North continues. Moreover, relative indicators fuel a discourse of hope, of the possibility of unlimited "progress," causing increasingly smaller proportional damages.

The other example regards reducing the percentage of people in extreme poverty during the last two centuries. This reduction represents important improvements in the well-being of those who come out of extreme poverty. However, when the threshold is USD$1.9/day, those who survive on USD$2/day are not in extreme poverty. Who decides that surviving on USD$2/day (or on USD$50/day, in a state of frequent frustration at trying to satisfy manufactured consumer needs) is not a state of extreme poverty? Analyzing thresholds together with the underlying distribution allows comparison all individuals of the population. Otherwise, only mentioning the reduction in the fraction or number of individuals within unfavorable categories may conceal that changes occur in intervals far from thresholds that decision-makers would accept for themselves in the global North.

Thresholds help to identify limits from which damages become irreversible: "Action has to be taken before irreversible changes in key Earth systems occur, which will require decision-making under uncertainty (panel 13) about the critical thresholds or rates of deterioration of these systems" (16). In this sense of warning of catastrophes, thresholds are helpful to raise awareness and generate changes. However, at the same time, they can promote policies of acceptable minimums to avoid only irreversible changes instead of promoting multispecies flourishing.

Policies of acceptable minimums are symptomatic of crisis that leads not to crossing or scarcely crossing minimum thresholds. A crisis that, when it becomes persistent, ceases to be explained and becomes an explanation (34). Thus, a previous level of causality that perpetuates the *status quo* is lost. This is evident in the report, in its fragmented descriptions of the threats to Planetary Health. For example, it presents changes in land use as a human action on the "environment", with deleterious effects on health, without considering their causes (16). From the perspective of One Health of Peripheries, the problem to solve resides in the capitalization of land that generates forced displacement of millions of people and animals, reduces biodiversity, and worsens the climate crisis.

The report identifies several causes of deterioration in health, and we agree with that identification. Our critique here is about the omission of previous causal levels. We also agree with the report in other points: the inconvenience of GDP as a measure of progress; technological improvements are not sufficient to reduce the environmental footprint because they can stimulate consumption and increase the footprint (rebound effect); governance transformations are necessary. We agree with a good part of the key messages and the conclusions. Our disagreement is, as shown by the previous decolonial viewpoint, in the interpretation of these messages and in the premises of the conclusions. From our reading, the report's proposal is convenient to preserve the *status quo* that makes the health of the planet ill.

The report calls for price stability and malnutrition management to fight hunger but not for food sovereignty and security: "[E]nsure stability of food prices and protect the vulnerable from variability that does occur; and tackle malnutrition" (16).

Again in a context of hunger, the proposal is to improve the access of the poor to technology to reduce inequalities, without discussing the control of technology or technological benchmarks; thus, helping oligopolies of the technology market to have more clients: "If these [modern] technologies are to make a useful contribution to the reduction of global hunger they have to both protect the environment and be accessible to farmers in low-income settings, otherwise inequities will persist and increase" (16).

In modern-colonial logic, it is essential to maintain epistemological hegemony. Those who do not exercise that hegemony must support it to benefit from it: "But to have a real effect, and to change the trajectory of planetary health, these local movements will need coherence, organization, and solidarity with the scientific and health communities" (16).

Those who exercise it have a voice and can be even more influential with the support of those who do not have voice: "The scientific and health communities, in turn, will be much more successful in influencing decision-makers who are feeling pressure for change from their constituents than they would without the support of civil society" (16).

In the medical care cost crisis, Private Medicine was clear and explicit in its intention to maintain the hegemony and avoid the participation of State Medicine (see the previous section). Similarly, the Rockefeller Commission is clear and explicit in its intention to maintain a top-down logic in which the owners of economic and scientific capital reserve for themselves the right to decide what is relevant: "Research funders and the academic community frame what questions get asked by scientists and can steer development of new ways of addressing major gaps in knowledge, scientific awareness, and academic focus" (16).

It is the modern logic imposed over centuries that says (note again the use of acceptable minimums and the meaning of acceptance): "At present trends, even with optimistic assumptions, the eradication of poverty (with a poverty line income of USD$5/day per person) will take 200 or 100 years for a poverty line of USD$1.25/day" (16). So there is no much to expect from modern trends.

It is necessary to overcome the modern crisis of civilization, starting from the first challenge identified in the report: "conceptual and empathy failures (imagination challenges)" (16).

ECOLOGY OF KNOWLEDGE

The previous decolonial reading of the report, pointing to some of its possibilities, limits and obstacles, commits us from the global South to understand deeper causal levels and transform the current relationship between nature, health, and society. One possibility, not only alternative but above all critical, is the "ecology of knowledge" proposed by Santos, framed in what he calls "epistemologies of the South," that is, the claim of the global South for "new processes of production, of valuing scientific and non-scientific valid knowledge, and of new relationships between different types of knowledge, based on the practices of the classes and social groups that have suffered, in a systematic way, destruction, oppression, and discrimination caused by capitalism, colonialism, and the naturalization of inequality" [translation is ours] (35).

According to Santos, non-Western forms of thought have been treated in an abyssal way by hegemonic modern Western thought, referring by abyssal to visible and invisible distinctions that divide social reality into two universes: one on this side of the line—the modern Western societies—and the other beyond the line—the colonial societies (35). For instance, in the field of modern knowledge, the visible line separates science from philosophy and theology, establishing the superiority of science through scientific criteria instead of reason or faith. The invisible line divides these types of knowledge from indigenous, popular, and other types of knowledge. The universe on the other side of the line disappears as reality. It becomes non-existent (in the sense of irrelevant and incomprehensible), radically excluded because it is beyond the universe of what the accepted conception of inclusion considers to be its other. In colonial societies, appropriation and violence segregate multispecies collectives, that is, subjects, nature, bodies, and knowledge that are on the side of denial (35).

Western modernity eliminates any reality that is on the other side of the line. Everything that does not fit in true-false or legal-illegal axes occurs in colonial zones (35). The abyssal lines are constitutive of the political and cultural relations based on the West and the interactions in the modern world-system (35). Thus, disqualification of non-modern knowledge globally underscores social and cognitive injustice.

By bringing these elements into the discussion about Planetary Health and One Health as alternatives for understanding and transforming the current relationship between nature, health, and society, the ecology of knowledge or post-abyssal thinking invites us to reflect and ask ourselves, among other things: if appropriation and violence established colonial societies, how can we now receive these philanthropic proposals under conditions of equality and justice instead of modernization imperatives? How to move toward a true post-abyssal thought?

Post-abyssal thinking takes the perspective of the other side of the line "precisely because the other side of the line has been the realm of the unthinkable in Western modernity" [translation is ours] (35). Post-abyssal thinking is learning from the epistemologies of the South, which confronts the "monoculture of modern science" against the ecology of knowledge. It frames science as one among many plural knowledge constituents, making possible a counter-hegemonic science to support marginalized multispecies collectives in their fight to get out of peripheries.

What is at stake is not only an abstract cognitive justice. The ecology of knowledge revalues the concrete interventions that different knowledge can offer (35). In it, knowledge hierarchies are context-dependent and not universal.

The ecology of knowledge invites us to build "an alternative of alternatives" based on permanent epistemological surveillance and intercultural translation. An alternative to avoid that Planetary Health, One Health, or any other approach become a renewed version of abyssal thinking, a softened revision of coloniality. From the ecology of knowledge we can stand against marginalizing apparatuses that create peripheries, unjust epidemiologic profiles, and only accept epistemologies of health from the global North.

THE DECOLONIAL-COLONIAL AXIS IN WHICH ONE HEALTH OF PERIPHERIES MUST BE PROMOTED

There are health-promoting indigenous lifestyles that serve as a reference to promote health in non-indigenous spaces. However, the adaptation of indigenous knowledge and experiences to non-indigenous peripheries leads to other types of practices (for instance, the Yanomami's respect and cultivation of edible mushrooms can inform agroecological practices but not simply scaled to supply the urban demand for such edibles). Not recognizing this transformation opens up colonizing possibilities that are counterproductive to health promotion. Globalization makes all locals contribute in some way to the reproduction of a colonial structure. Therefore, any place of decolonial resistance also has a colonial side, no matter how small. From this situation, one of the tasks for the decolonial promotion of One Health of Peripheries is to deconstruct, through the ecology of knowledge, the marginalizing apparatuses underlying health inequities suffered by multiple species (20). These are the issues addressed in this section.

In One Health of Peripheries, the peripheries are a symbolic category expressed in epidemiologic profiles (20). The global South is a heterogeneous geopolitical periphery within that category. Its health dimension has been theorized and transformed by Latin American Social Medicine since the 70s, and nowadays in the form of Critical Epidemiology, Collective Health, and South-South International Health. In a broader scope, this periphery, the global South, has promoted worldviews and lifestyles that in current rhetoric could be deemed sustainable, healthy, and instances of good living (36).

The indigenous worldviews and lifestyles, as well as the initiatives that have been based on them in the attempt to transform the institutional arrangement established and maintained by modernity, serve as a reference to promote One Health of Peripheries. Take good living (buen vivir) as an example, a concept from the Aimará *suma qamaña* and the Quechua *sumak kawsay*, incorporated in the constitutions of Bolivia and Ecuador (36). Although a discussion of good living is beyond the scope of this manuscript, we stress that in its generality it is a holistic proposal of collective-care exercised by a plural totality in which local communities are not peripheral (36). On the contrary, Planetary Health aims to control natural systems and keep the global South in a subaltern position. In it, the only allowed aspiration is to benefit from the epistemological, scientific, and technological transfers of the global North.

In institutional terms, the meaning of good living has been substantially transformed. Ecuador and Bolivia incorporated the concept in the constitution in 2008 and 2009, respectively, and just this by itself is a symbolic recognition of indigenous peoples. However, Solón point that in practice the recognized rights to nature and Mother Earth ended up being secondary to extractivist interests; the rhetoric of good living began to coexist with income redistribution policies that supported capitalist interests, allowed for the growth of oligopolies and encouraged patronage with some indigenous sectors (36). Paradoxically, under an indigenous government, it was possible to increase the acceptance of the modernization rejected for centuries, and the percentage of people who consider themselves indigenous fell from 62 to 41% between 1990 and 2013 (36). This experience of good living institutionalization shows that despite the marked differences between projects with opposite origins in the decolonial-colonial spectrum, the distance between discourses and implemented practices affects both poles of the spectrum. Contamination between the poles gives rise to the body of the spectrum.

The promotion of One Health of Peripheries must recognize and anticipate the distance between discourses and practices and the contamination between the decolonial and the colonial. Thus, it is convenient to consider the historical-social processes that produce and reproduce social organization levels and their corresponding epidemiological profiles. Following Samaja (37), individuals are in the lower social organization level, and the world-system is in the upper level. Between the two, there are several levels (family, community, political-administrative territorial divisions, contractual associations, and other institutions). Upper levels reproduce themselves by regulating the lower, but this regulation is not all-encompassing, allowing lower levels to produce partial changes in upper ones (37). The upper level reproduces a colonial structure through the regulation it exercises in lower levels, and these can partially change that structure through decolonial practices. This is the so-called social determination framing collective health epistemology, and as it has unavoidable multispecies dimensions, it also frames One Health of Peripheries (20). The promotion of One Health of Peripheries must occur in such dialectical movement, noting that partial decolonial changes means partial reproduction of coloniality. Such decolonial-colonial contradiction does not spare One Health of Peripheries, so proposals of promotion must take it into account to better match discourses and material possibilities.

The set of practices exercised from a given position has decolonial *and* colonial elements instead of decolonial *or* colonial elements. So indigenous good living and the neoliberal rhetoric of good living differ in the direction and intensity of bias toward the decolonial-colonial extremes. Similarly, collective health education programs are not totally different from colonial higher education or Preventive Medicine in its colonial origins. The degree of difference depends on how close they get to the respective extremes.

The conditions of possibility of the peripheral cartography (20) also condition the decolonial promotion of One Health of Peripheries. Exercising such promotion from within and outside that cartography challenges the center-periphery distinction through social determination movements. It is a utopian and dialectical promotion that, by centralizing peripheries, somehow reinforces the mentioned distinction and creates other peripheries. It is a *glocal* movement between localization and globalization (38).

So far, it may not be clear why it is convenient to add "One" to "Health of Peripheries." It might well be Planetary Health of Peripheries to highlight the glocal movement between the global (planetary) and the local (peripheries). One Health is a conceptual framework that, like Planetary Health, brings together statements in favor of health for all, but in practice reinforces the myth of modernity. In fact, One World One Health™ is a registered trademark, created from the Wildlife Conservation Society conference, established in 2004 at Rockefeller University (39, 40). The colonial venue for the event may seem like an isolated event that does not link the Wildlife Conservation Society to coloniality. But suffice it to remember that at the time of Rockefeller institutions' foundation, the Bronx Zoo was exhibiting Ota Benga (the young Mbuti from what is now the Democratic Republic of the Congo). The Wildlife Conservation Society waited until 2020 to issue a public apology for its responsibility in the exhibition and the position of two of its founders, Madison Grant and Henry Fairfield Osborn, who were also founders of the American Eugenics Society and stood in favor of defendants in the Nuremberg trials (41). Unfortunately, the apology did not entirely reproach the colonial tradition of exhibiting other animals, perhaps mistaking exhibition as a necessary condition for wildlife conservation. They did not see anything wrong with exhibiting Ota Benga a century ago, and now they do not condemn the same practice with nonhuman animals. Hopefully, they will not need another century to abolish that practice.

In light of the colonial roots of One Health, which goes beyond what we briefly outlined (18), a decolonial proposal based on the One Health concept may seem contradictory. However, it is worth noting that One Health of Peripheries gives other meanings to One Health (20) and metabolizes contradictions through its social determination and the ecology of knowledge. Decolonizing One Health adds plurality to the Latin American health movements, thus increasing the strength and resilience of decolonial resistance.

In One Health, health is more-than-human, and it involves three inextricably related domains: human health, animal health, and environmental health (42). This differs from Planetary Health in which health is human and natural systems have instrumental value as determinants of health (16); the value of animals is instrumental to the extent that they contribute to the maintenance of natural systems favorable to human health. In One Health approaches, animals are also predominantly instrumental to human health (42); however, they appear as carriers of health, and animal health takes a fundamental role in a health that is not just human.

Biomedicine does not question the existence of physiopathological processes in animals in the same way that epidemiology does not question the existence of transmission dynamics between animals or between animals and humans. As any other species, humans have similarities and differences with the individual and population biological processes of health-disease of other species.

The attribution of lower moral status to non-human animals for the simple fact of not belonging to the human species (speciesism) is as arbitrary as giving less value to some humans because of the race or gender attributes tied to them [racism and sexism] (43). Attempts to justify the inferior status of animals sometimes base arguments on the greater cognitive capacity of humans. However, many animals surpass the cognition of severely disabled humans, leading to justifications of moral differentiation in which not all humans are of equal value and some are of less value than many animals (43). Based on different criteria of cognitive capacity, the moral justifications to completely separate human beings from the rest of the animals are also problematic, revealing what Agamben calls the anthropological machine, an inclusion-exclusion apparatus to separate humans from other animals, that the more it is renewed in the attempt to eliminate aporias, the more it reveals its arbitrariness and contradiction (44).

The distinction between humans and non-humans is a marginalizing apparatus in the service of domination. It is a central dichotomy of modernity (45) through which dehumanization/animalization is all the more, the greater the distance of a being from the Western heterosexual male referent.

It is epistemic violence that marginalizes humans, denies the subjectivity of other animals, and reconfigures animality as black, indigenous (45), female, and not heterosexual. In other words, it is more than human violence, with victims of multiple species. Animals are animalized insofar as they are inscribed in such animal space of colonial domination (45). The animalizing apparatus is also applied through colonial health practices that legitimize domination and represent it as a benevolent act.

In his analysis of 19th-century slave farms in Cuba, Camacho describes how Chateusalins, in his Vademecum of Cuban landowners, recommended masters of female slaves "to avoid giving them a harsh treatment," to give them "better food than before" and to "protect them with delicacies and concessions to encourage them to preserve the product of their conception and raise their little offspring" [translation is ours] (46). In order to convince the masters, Chateusalins stated: "I know that in all farms where it reigns goodness and sweetness and attentions of the masters toward the blacks, there are many happy blacks whose mothers express their happiness in their singing and smiling faces [...] We have seen the books of gains and losses in which it appears that far from suffering a loss of 5.5%, which is what is generally calculated in this class of farms, it has been, on the contrary, an increase from 4.5 to 5.5%, which shows the advantages that the careful treatment given to blacks brings with it" [translations is ours] (46).

This production-health binomial was framed in what we might understand as an epidemiological-zootechnical approach for slave control. Compartmentalization of facilities; populations divided according to demographic criteria of productive and reproductive interest; classification and monitoring of morbidity and mortality; prevention of communicable diseases; reproductive selection (genetic improvement); hygiene, nutrition, socialization, and other generic practices to reduce losses of biological capital [see the documented analyzes of such practices by Smithers and Camacho (46, 47)].

The rationalizing discourse of such an approach—statistics, efficiency, evidence—sought above all productivity, adding value to animalized commodities. The slaves were objects of knowledge and professional practices (medicine, statistics, anthropology) that produced "truths" on which the political and economic regime of the plantation depended (46). However, behind the pretense of truth and rationality, there was prejudice and contradiction. As shown by the Camacho's analysis of the medical anthropology of Dumont (48), the medical literature provided descriptions of the black race as "prone to contracting several diseases," while the anthropological one contributed with assertions of the type "lazy by nature," "all blacks are polygamous," "all are fetishists" [translations are ours] (46). On the other hand, the prescriptions of kindness and attention to the "human" needs of the slaves ironically opposed animalization, but this did not prevent its practice. The concern with the health of the slaves was a concern to maintain the profitability of their bodies and prevent them from transmitting diseases to the masters and their families, whose health did have value in itself. The epidemiology and zootechnics of slaves coexisted with torture practices to make them docile; their affections were irrelevant, except as instruments to increase productive and reproductive performance, through persuasive practices also reported in the medical literature (46). The advertisements of slaves with specific phenotypic characteristics and of drugs authorized by the government against diseases affecting slaves (46) showed how animalization was naturalized and legitimized by the State, the media, and the knowledge produced by epistemic authorities.

In essence, the discourse of slaves epidemiology and zootechnics is equivalent to the contemporary discourse of animal production epidemiology and animal science. Similarly, within animal welfare science we find benevolence narratives that legitimize livestock exploitation and add value to live commodities. In both cases (slaves and livestock), oppressive relationships are naturalized, and the better performance of productive and sanitary parameters serves as an indicator of improvements in well-being.

By deconstructing marginalizing apparatuses and giving rise to multispecies collectives in which the other is not a commodity and its subjectivity is cared for and respected, the possibilities of promotion cease to be variations of degree within a restrictive peripheral space and become variations of kind. Thus, abolishing slavery is a leap of promotion, allowing lifestyles—processes, capabilities, and health conditions—unattainable through the health practices restricted to the periphery of slavery. As health is inherently determined by value judgments, problematizing these judgments is essential to break the margins that limit the promotion of One Health of Peripheries.

SEVEN ACTIONS OF DECOLONIAL PROMOTION OF ONE HEALTH OF PERIPHERIES

The Ottawa Charter [see in McPhail-Bell et al. (49) a postcolonial critique of the Charter] proposed five actions to promote health: (1) build healthy public policy; (2) create supportive environments; (3) strengthen community actions; (4) develop personal skills, and; (5) reorient health services (50). Redefining and complementing these actions with another two lead to the promotion of One Health of Peripheries: (1) deconstruct marginalizing apparatuses; (2) enrich the ecology of knowledge; (3) build healthy multispecies public policy; (4) create supportive environments; (5) strengthen multispecies community actions; (6) develop individual capabilities in multiple species, and; (7) reorient multispecies health services. The deconstruction of marginalizing apparatuses is transversal to the other actions, and in that sense, we do not need to include it as a separate action. However, we can do the same with the others. Although one is transversal to the others, its explicit recognition reinforces its importance.

The seven actions require overcoming the primary challenge identified by the Lancet Commission on Planetary Health: "conceptual and empathy failures (imagination challenges)" (16), something particularly challenging within coloniality. However, for the very same reason, they contribute to the decolonial turn. A turn that requires imagination and multispecies empathy, and might be seen as a turn from Capitalocene to Chthulocene [see in Haraway (51) a discussion of the Anthropocene, Capitalocene, and Chthulocene].

Despite the difficulties in promoting One Health of Peripheries, there are precedents for each of its seven actions. The first action deconstructs marginalization from a health perspective and finds support in the more-than-human sociology (52–55), anthropology (56), biopolitics (44, 57, 58), critical studies (59), social work (60, 61), theories justice (62–64), and moral philosophy (65, 66) to name a few areas. The second action opens space to the epistemologies of the indigenous and non-indigenous global South (5), remembering that for the holistic sustainability "discovered" by Planetary Health, there are indigenous versions with centuries of successful experiences and that animalization is a colonial apparatus that oppresses human and non-human animals. Albeit insufficient, there is already public policy support for living cities (67), biodiversity and indigenous territories. More-than-human theories of labor (63), food sovereignty and security, sustainable agriculture, response to disasters, and degrowth perspectives can strengthen and expand this type of policies (third and fourth action). Moreover, participatory policies exist in various settings, community practices abound in the global South, and animal and environmental activism has been growing. This gives practical support to multispecies intersectionality (20, 68), from which the fifth action can be worked out. An outstanding theoretical framework of justice is that of capabilities, already elaborated by Nussbaum to consider disability, nationality, and non-human animal species (62). Therefore, the sixth action, which in the version of the Ottawa Charter (fourth action) might seem applicable only to humans, has a robust theoretical support to consider peripheral subjects of different species. Even the seventh action has precedents. In Brazil, for instance, the Unified Health System (national health system), in addition to having units dedicated to the epidemiological surveillance of zoonoses that also promote responsible care for animals, has dependencies dedicated to the health and protection of domestic animals. These dependencies have specific attributions regarding rescuing, sheltering and adoption, population control, and administration of veterinary hospitals offering free services (69). Undoubtedly, some of these precedents need reassessments and sound plural participation to preclude or stop being stratagems at the service of non-collective interests. But at the same time, they are precedents that in some way have locally fractured peripheries-making margins.

CONCLUSION

Coloniality did not end with colonialism, and the myth of modernity is at the kernel of the crisis of civilization we are living. Philanthrocapitalism allows material gains that significantly improve the livelihood of the poorest because they are in conditions in which small aids make a big difference, even if they continue in poverty. Those improvements are convenient to legitimize vast accumulations of wealth by a few rich philanthropists and massive deprivation suffered by billions (in 2019, the wealth concentrated by 0.000028% of the population was greater than that of 59.7%). Philanthrocapitalism in health has been a strategy to reinforce colonial epistemology and favor the interests of the global North, dictating what should be understood by health, how health problems should be solved, and how people should live to avoid them. The Rockefeller Foundation has been an icon of philanthrocapitalism, shaping Latin American health through public policy, education, and research. One of the Foundation's recent proposals is Planetary Health, also framed in the rhetoric of the global North.

The ecology of knowledge, with its intercultural translation, is a response from the global South to repair the damage of coloniality. It encompasses indigenous and popular knowledge, Latin American health movements, and the counter-hegemonic use of science. It can also make counter-hegemonic use of Planetary Health and One Health. An example of such use is One Health of Peripheries, at the same time a reconfiguration of One Health and Latin American health movements, strongly opposed animalization, that is to say, to the colonial space oppressing animals and peripheral human groups. Extending the scope and the meaning of the Ottawa Charter proposal, the decolonial promotion of One Health of Peripheries comprise seven actions: (1) deconstruct apparatuses of marginalization; (2) enrich the ecology of knowledge; (3) build healthy multispecies public policy; (4) create supportive environments; (5) strengthen multispecies community actions; (6) develop individual capabilities in multiple species, and; (7) reorient multispecies health services.

DATA AVAILABILITY STATEMENT

The original contributions generated for the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

AUTHOR CONTRIBUTIONS

All authors contributed to the article and approved the submitted version.

FUNDING

Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES, Coordination for the Improvement of Higher Education Personnel).

ACKNOWLEDGMENTS

We acknowledge the One Health of Peripheries network (Saúde Única emPeriferias - SUP-FMVZ-USP, www.saudeunicaemperiferias.com) and the Research group on Peripheries (nPeriferias-IEA-USP, www.iea.usp.br/pesquisa/grupos-pesquisa/nperiferias).

REFERENCES

1. Dussel E. Eurocentrism and modernity (introduction to the Frankfurt lectures). *Bound.* (1993) 20:65. doi: 10.2307/303341
2. Quijano A. Coloniality and modernity/rationality. *Cult Stud.* (2007) 21:168–178. doi: 10.1080/09502380601164353
3. Mignolo W. *The Darker Side of Western Modernity: Global Futures, Decolonial Options*. London: Duke University Press (2011). doi: 10.2307/j.ctv125jqbw
4. Dussel E. *1492 El encubrimiento del Otro: hacia el orgien del "mito de la Modernidad."* La Paz: Plural editores (1994).
5. Santos B de S, Meneses MP. *Epistemologias do Sul*. São Paulo: Cortez Editora (2010).
6. Mignolo WD. Citizenship, knowledge, and the limits of humanity. *Am Lit Hist.* (2006) 18:312–31. doi: 10.1093/alh/ajj019
7. Grosfoguel R. Caos sistémico, crisis civilizatoria y proyectos descoloniales: pensar más allá del proceso civilizatorio de la modernidad/colonialidad. *Tabula Rasa.* (2016) 25:153–74. doi: 10.25058/20112742.79
8. Arouca S. *O Dilema Preventivista: Contribuição Para a Compreensão e Crítica da Medicina Preventiva*. Rio de Janeiro: UNESP Eitora (2003). doi: 10.7476/9788575416105
9. Vieira-da-Silva LM. *O Campo da Saúde Coletiva: Gênese, Transformações e Articulações Coma Reforma Sanitária*. Salvador: Editora da UFBA, Editora Fiocruz (2018).
10. Moreira MC. The Rockefeller Foundation and the construction of a professional identity in nursing during Brazil's first Republic. *Hist Cienc Saude Manguinhos.* (1998) 5:621–45. doi: 10.1590/S0104-59701999000100005
11. Paim JS, De Almeida Filho N. Saúde coletiva: Uma "nova saúde pública" ou campo aberto a novos paradigmas? *Rev Saude Publ.* (1998) 32:299–316. doi: 10.1590/S0034-89101998000400001
12. Breilh J. *Epidemiologia Crítica: Ciência Emancipadora e Intercultural.* Translated by Vera Ribeiro. Rio de Janeiro: Editora Fiocruz (2006).
13. Basile G. *La Salud Internacional Sur Sur: Hacia un Giro Decolonial y Epistemológico*. La Plata: CLASCO (2018).
14. Acero-AM. Zoonosis y otros problemas de salud pública relacionados con los animales: Reflexiones a propósito de sus aproximaciones teóricas y metodológicas. *Rev Gerenc y Polit Salud.* (2016) 15:232–45. doi: 10.11144/Javeriana.rgyps15-31.zops
15. Andrade FAT. *Propuesta Teórico-Metodológica de Epidemiología Crítica de la Salud Animal, Primer Acercamiento de Aplicación en el Caso de la Fiebre Aftosa en el Ecuador*. Quito: Universidad Andina Simón Bolivar (2019).
16. Whitmee S, Haines A, Beyrer C, Boltz F, Capon AG, De Souza Dias BF, et al. Safeguarding human health in the Anthropocene epoch: report of the Rockefeller Foundation-Lancet Commission on planetary health. *Lancet.* (2015) 386:1973–2028. doi: 10.1016/S0140-6736(15)60901-1
17. Davis A, Sharp J. Rethinking one health: emergent human, animal and environmental assemblages. *Soc Sci Med.* (2020) 258:113093. doi: 10.1016/j.socscimed.2020.113093
18. Lainé N, Morand S. Linking humans, their animals, and the environment *again* : a decolonized and more-than-human approach to "One Health." *Parasite.* (2020) 27:55. doi: 10.1051/parasite/2020055
19. Prescott SL, Logan AC. Planetary health: from the wellspring of holistic medicine to personal and public health imperative. *Explore.* (2019) 15:98–106. doi: 10.1016/j.explore.2018.09.002
20. Baquero OS. One Health of peripheries: biopolitics, social determination, and field of praxis. *SciELO Prepr.* (2021) 1–21. doi: 10.1590/SciELOPreprints.2019
21. Daros W. La creación de la modernidad. Nuevos deseos e intereses de la humanidad. *Invenio.* (2015) 18:51–65.
22. Jiménez RG. La modernidad: sintomatología de los procesos modernizantes en las sociedades. *Temas Cienc Tecnol.* (1998) 2:55–67.
23. Grosfoguel R. The epistemic decolonial turn: beyond political-economy paradigms. *Cult Stud.* (2007) 21:211–23. doi: 10.1080/09502380601162514
24. Escobar A. Worlds and knowledges otherwise: the Latin American modernity/coloniality research program. *Cult Stud.* (2007) 21:179–210. doi: 10.1080/09502380601162506
25. Ballestrin L. América Latina e o giro decolonial. *Rev Bras Ciência Política.* (2013) 2013:89–117. doi: 10.1590/S0103-33522013000200004
26. Dussel E. Europa, modernidad y eurocentrismo. In: Lander E, editors. *La colonialidad del saber: eurocentrismo y ciencias sociales. Perspectivas latinoamericanas*. Buenos Aires: Consejo Latinoamericano de Ciencias Sociales (1993).
27. Quijano A. Colonialidade do poder e classificação social. In: de S. Santos B, Meneses MP, editors. *Epistemologias do Sul*. São Paulo: Cortez Editora (2019). p. 84–130.
28. Coffey C, Espinoza Revollo P, Harvey R, Lawson M, Parvez Butt A, Piaget K, et al. *Time to Care: Unpaid and Underpaid Care Work and the Global Inequality Crisis*. Oxford (2020). doi: 10.21201/2020.5419
29. Guilhot N. Une vocation philanthropique. *Actes Rech Sci Soc.* (2004) 151–2:36. doi: 10.3917/arss.151.0036
30. Tota AP. *O imperialismo sedutor: a americanização do Brasil na época da Segunda Guerra*. São Paulo: Companhia das Letras (2000).
31. Fishbein M, Bierring WL. *A history of the American Medical Association 1847 to 1947*. Philadelphia, PA: Saunders (1947).
32. Redvers N, Yellow Bird M, Quinn D, Yunkaporta T, Arabena K. Molecular decolonization: an indigenous microcosm perspective of planetary health. *Int J Environ Res Public Health.* (2020) 17:4586. doi: 10.3390/ijerph17124586
33. Redvers N, Poelina A, Schultz C, Kobei DM, Githaiga C, Perdrisat M, et al. Indigenous natural and first law in planetary health. *Challenges.* (2020) 11:29. doi: 10.3390/challe11020029
34. Santos B. *Vírus: tudo o que é sólido se desfaz no ar*. (2020). Available online at: https://www.sul21.com.br/opiniaopublica/2020/03/virus-tudo-o-que-e-solido-se-desfaz-no-ar-por-boaventura-de-sousa-santos/ (accessed November 27, 2020).
35. Santos B de S. Para além do pensamento abissal: das linhas globais a uma ecologia de saberes In: Santos B de S, Meneses MP, editors. *Epistemologias do Sul*. São Paulo: Coertez Editora (2007). p. 31–83.
36. Solon P. *Alternativas sistêmicas: Bem Viver, decrescimento, comuns, ecofeminismo, direitos da Mãe Terra e desglobalização*. São Paulo: Elefante Editora (2019).
37. Samaja J. *Epistemología de la salud: reproducción social, subjetividad y transdisciplina*. Buenos Aires: Lugar (2007).
38. Roudometof V. Theorizing glocalization. *Eur J Soc Theory.* (2016) 19:391–408. doi: 10.1177/1368431015605443
39. Woldehanna S, Zimicki S. An expanded one health model: integrating social science and one health to inform study of the human-animal interface. *Soc Sci Med.* (2015) 129:87–95. doi: 10.1016/j.socscimed.2014.10.059
40. Wildlife Conservation Society. *One World, One Health TM* [Internet]. New York, NY: Wildlife Conservation Society (2020).
41. Wildlife Conservation Society. *A Statement from the Wildlife Conservation Society. WCSNewsroom.* (2020). Available online at: https://newsroom.wcs.org/News-Releases/articleType/ArticleView/articleId/14648/A-Statement-from-the-Wildlife-Conservation-Society.aspx (accessed November 7, 2020).
42. WHO, OIE, FAO. *Taking a Multisectoral, One Health Approach: A Tripartite Guide to Addressing Zoonotic Diseases in Countries.* Rome (2019).
43. Singer P. Speciesism and moral status. *Metaphilosophy.* (2009) 40:567–81. doi: 10.1111/j.1467-9973.2009.01608.x
44. Agamben G. *The Open: Man and Animal*. Stanford, CA: Stanford University Press (2004).
45. Belcourt BR. Animal bodies, colonial subjects: (re)locating animality in decolonial thought. *Societies.* (2014) 5:1–11. doi: 10.3390/soc5010001
46. Camacho J. Los criaderos de esclavos: medicina, cuerpos y sexualidad en los ingenios de Cuba. *Hispanófila.* (2020) 188:3–18. doi: 10.1353/hsf.2020.0014
47. Smithers G. *Slave Breeding: Sex, Violence, and Memory in African American History*. Gainesville, FL: University Press of Florida (2012). doi: 10.5744/florida/9780813042381.001.0001
48. Dumont H. *Antropología y patología comparadas de los negros esclavos.* Translated by Israel Castellanos. La Habana: Habana (1922).
49. McPhail-Bell K, Fredericks B, Brough M. Beyond the accolades: a postcolonial critique of the foundations of the Ottawa Charter. *Global Health Promot.* (2013) 20:22–9. doi: 10.1177/1757975913490427
50. World Health Organization. *Milestones in Health Promotion: Statements from Global Conferences*. Geneva, FL: WHO Press (2009).
51. Haraway D. *Staying With the Trouble. Making Kin in the Chtulucene*. Durham: Duke University Press (2016). doi: 10.2307/j.ctv11cw25q

52. Peggs K. *Animals and Sociology*. London: Palgrave Macmillan (2012). doi: 10.1057/9780230377271
53. Tuomivaara S. *Animals in the Sociologies of Westermarck and Durkheim*. London: Palgrave Macmillan (2019). doi: 10.1007/978-3-030-26863-3
54. Pyyhtinen O. *More-Than-Human Sociology: A New Sociological Imagination*. New York, NY: Palgrave Macmillan (2016). doi: 10.1057/9781137531841
55. Sayes E. Actor-network theory and methodology: just what does it mean to say that nonhumans have agency? *Soc Stud Sci.* (2014) 44:134–49. doi: 10.1177/0306312713511867
56. Kirksey SE, Helmreich S. The emergence of multispecies ethnography. *Cult Anthropol.* (2010) 25:545–76. doi: 10.1111/j.1548-1360.2010.01069.x
57. Asdal K, Druglito T, Hinchliffe S. Humans, animals and biopolitics. In: Asdal K, Druglito T, Hinchliffe S, editors. *The More-Than-Human Condition*. New York, NY: Roudlege (2016). doi: 10.4324/9781315587639
58. Wadiwel DJ. *The War Against Animals*. Leiden: Brill (2015). doi: 10.1163/9789004300422
59. Taylor N, Twine R. *The Rise of Critical Animal Studies: From The Margins to The Centre*. New York, NY: Routledge (2014). doi: 10.4324/9780203797631
60. Ryan T. *Animals in Social Work: Why and How They Matter*. New York, NY: Palgrave Macmillan (2014).
61. Ryan T. *Animals and Social Work: A Moral Introduction*. New York, NY: Palgrave Macmillan (2011). doi: 10.1057/9780230306868
62. Nussbaum M. *Frontiers of Justice: Disability, Nationality and Species Membership*. Cambridge: Harvard University Press (2003).
63. Blattner CE, Coulter K, Kymlicka W. *Animal Labour: A New Frontier of Interspecies Justice?*. Oxford: Oxford University Press (2020). doi: 10.1093/oso/9780198846192.001.0001
64. Celermajer D, Schlosberg D, Rickards L, Stewart-Harawira M, Thaler M, Tschakert P, et al. Multispecies justice: theories, challenges, and a research agenda for environmental politics. *Env Polit.* (2020) 30:1–22. doi: 10.1080/09644016.2020.1827608
65. Johnson L, White TI, Bernstein MH, Peggs K. *The Palgrave Handbook of Practical Animal Ethics*. London: Palgrave Macmillan (2018).
66. Singer P. *Animal Liberation: The Definite Classic of Animal Movement*. New York, NY: Harper Perennial Modern Classics (2009).
67. Hinchliffe S, Whatmore S. Living cities: towards a politics of conviviality. *Sci Cult.* (2006) 15:123–38. doi: 10.1080/09505430600707988
68. Bauer GR. Incorporating intersectionality theory into population health research methodology: challenges and the potential to advance health equity. *Soc Sci Med.* (2014) 110:10–7. doi: 10.1016/j.socscimed.2014.03.022
69. Prefeitura do Município de São Paulo. *DECRETO No 59.685, DE 13 DE AGOSTO DE 2020.* (2020).

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Veterinary Science

PERSPECTIVE
published: 14 June 2021
doi: 10.3389/fvets.2021.641634

The Behavior of Consumers and Producers of Food of Animal Origin and Their Impacts in One Health

*Natália Maramarque Nespolo**

Veterinary Medicine Nucleus, Federal University of Sergipe, Nossa Senhora da Glória, Brazil

Most people consume animal foods, for example meats, but few are concerned with the quality and origin of these products. Many studies point out hygiene problems of these foods after production; however, the lack of knowledge of the consumers of animal products about the importance of hygienic-sanitary control during the production process can lead them to a bad choice when buying these products and, consequently, expose themselves to the risk of acquiring many diseases, such as zoonosis. In this perspective, the objective of this work is to reflect about the consumers' role in the production of safe food of animal origin and to show that the population's health education is necessary and urgent. Only by helping the consumers to obtain knowledge about the production of animal products origin will there be a change in consumption habits, preventing the ingestion of contaminated foods that can cause damage to human health and to the environment, consequently, promoting one's health.

Keywords: food, zoonosis, health, education, animal products

OPEN ACCESS

Edited by:
Christina Pettan-Brewer, University of Washington, United States

Reviewed by:
Kumaragurubaran Karthik, Tamil Nadu Veterinary and Animal Sciences University, India
Getahun E. Agga, United States Department of Agriculture, United States

***Correspondence:**
Natália Maramarque Nespolo
natinespolo@yahoo.com.br

Specialty section:
This article was submitted to Veterinary Infectious Diseases, a section of the journal Frontiers in Veterinary Science

Received: *14 December 2020*
Accepted: *12 May 2021*
Published: *14 June 2021*

Citation:
Nespolo NM (2021) The Behavior of Consumers and Producers of Food of Animal Origin and Their Impacts in One Health. Front. Vet. Sci. 8:641634. doi: 10.3389/fvets.2021.641634

INTRODUCTION

Protein from animal sources, especially meat, is an important source of nutrition for many people around the world, and to produce them in a sustainable way is one of the challenges in the coming decades (1). Foodborne diseases are a serious global health problem (2), and in developing countries, most people are not concerned about the norms in the processing and packaging of the food (3) that they will consume and/or offer to other people to eat (4, 5). Due to this carelessness or lack of knowledge about safety production and handling of food of animal origin at the time of purchase, people do not know whether they are buying clandestine or manufactured products that have a good hygienic-sanitary standard supported by legislation and guarantee safe consumption.

Some questions about food of animal origin are important and should be considered at the time of purchase or consumption, such as what would be the origin of the food that I am buying? Do I search and know how to identify in the label if the products of animal origin have been inspected and produced by hygienic-sanitary standards? Would I buy the product if I knew that it is harmful to health and to the environment just because it is cheaper? Do I know the diseases that I can get if I consume a contaminated product from animal sources?

Unfortunately, most people do not have the answer or the habit of thinking about these questions, mainly in developing countries. In Latin America, there are many researches related to the profile and behavior of the consumer of food from animal sources, and it showed that most of the people do not worry about the animals' sanitary conditions and the good hygienic practices during the production process (2, 4–10). They care most about the color, tenderness, and price of the food, and in some regions, it is explained by the low education of the population, including people who are analphabet (4). In Brazil, a study about consumer perception of risks associated with food, safety and traceability showed that some consumers are concerned about health risks linked to animal products, but they have a wrong idea about the concept of hygienic-sanitary factors, as could be seen in the phrases like "A product that is not so perishable, such as honey, could buy both from the farm and from the supermarket, as it does not offer such a great risk" and "the cheese on the farm tastes better than the supermarket" (6). Therefore, if the consumers do not know about the hygienic and sanitary aspects of the food of animal origin that they will eat, will the producers and farmers really do care about it?

In addition to the lack of knowledge, the consumers are also false-information hostages about the product they will purchase and/or consume (6, 10) and end up not making the best choice at the market. Disinformation is often spread by famous digital influencers (11) who are not experts in the production of food of animal origin. This lack of scientific knowledge of the consumers ends up harming their own health and the economy, because in addition to running the risk of eating contaminated food, many also stop eating meat and other animal products due to the negative influence of lay people on the subject or motivated by ethical and moral issues, like their own beliefs in animal welfare and environmental impact of production systems (10, 12, 13).

Thus, the objective of this work is to reflect about the role of the consumers and producers in the production of safe food from animal sources and to show the necessity and urgency of education on health, and to have changes in people's beliefs and consumption habits. Thus, it will help people to know more about the proper production of food of animal origin and, consequently, to choose better products at the time of purchase, thereby preventing the ingestion of contaminated foods that can cause human diseases and promoting producers to have good manufacturing practices, promoting one's health.

HYGIENE

Basic personal hygiene habits, despite being simple, still are extremely important and must be acquired in childhood because children, besides growing up with these habits, are good disseminators of information to other people (14). The new Coronavirus pandemic highlighted the importance of hygiene habits in early childhood education (15). A primordial habit to produce food safely is to wash hands properly, especially before handling (3, 16). Food handlers are often associated with foodborne disease outbreaks and are estimated to contribute 7–20% of the outbreaks (17). Improper poor personal hygiene of food handlers contributes most to disease incidence (16).

Personal hygiene habits are also different between genders, since men are less likely to wash their hands after going to the bathroom than are women (17). This is an important data for producers of food of animal origin, because most people who work in the production area are men, as shown in a research made in Brazil about employment and occupational accidents in the slaughterhouse (18). The simple act of washing hands can prevent many diseases carried by food (16, 17).

Another bottleneck is in practicing hygiene during the production of food from animal sources (19), that is, whether the producers are practicing correct sanitation as regards the environment, the equipment, and the materials to not allow food contamination (3, 17). The use of potable water and the constant monitoring of its quality in food manufacturing are extremely important (3, 17) but are largely overlooked by consumers. Imagine if the cheese you eat was made with water from a river polluted by sewage, would you eat it?

Some people in developing countries eat fecal bacteria for a long time, and people and the municipal government do anything to change it, as shown in the state of Sergipe in Brazil. In 2008, a study showed the results of the analyses of 60 rennet cheeses commercialized in Aracaju city; the samples presented *Salmonella* spp. (26.7%), coagulase-positive Staphylococcus (46.7%), total coliforms (93.3%) with values from 8.0×10^2 to 1.23×10^4 NMP/g, and thermotolerant coliforms from 2.72×10^2 to 1.12×10^3 NMP/g (20). In 2019, another research was carried out in the same city with 18 rennet cheeses in which, after 11 years, the cheeses continued to be commercialized with coliforms (3.8×10^3 and 1.1×10^7 CFU/g), *Staphylococcus* spp. (8.0×10^2 to 1.2×10^6 CFU/g), *S. aureus* (50%), pathogenic *E. coli* (16.67%), and *Salmonella* (5.55%) (21).

Other factors, such as technological ones, also help in preserving perishable products, for example the room's temperature control (3, 16, 19). Together with the poor personal hygiene of food handlers, improper holding temperature also contributed most to disease incidence (16). Commonly, the researchers are concerned about the hygienic conditions of the products during or after the sale (3, 16), which can also beget foodborne diseases due to incorrect handling (2), but it is substantial to care about the flowchart production before the sale too. Thus, it is important to use the farm-to-fork strategies to produce hygienic food and to keep the consumers and the planet healthy (17).

All details, even the minute ones, must be carefully considered to produce food from animal sources safely. For this reason, there are quality-control programs in industries, such as good manufacturing practices (GMP) and hazard analysis and critical control points (HACCP) (17, 19, 22), that allow the organization and standardization of the production. Hence, it ensures equal hygienic and sanitary conditions during the manufacturing process, and it allows the identification of probable dangers to reduce them to acceptable levels or cut them out (17, 19). However, few people know about these programs, and they are not present in the clandestine production of food from animal sources. The illicit food process is totally disorganized and dirty, leaving out the conduct of some (or several) precautions and allowing the contamination of the food produced (23) (**Figure 1**).

ANIMAL HEALTH AND WELFARE

To produce food safely for human consumption, another bottleneck is in selecting healthy animals. Most people know that veterinarians work at farms, but they do not know that these professionals must be present in food industries also.

FIGURE 1 | Absence of quality-control programs of a clandestine bovine slaughter, showing a disorganized, and dirty production (24).

Inside the slaughterhouse, the veterinarians are responsible for the inspection of the animals (25), and if the animal or the carcass shows any sign of disease or contamination, they will determine if the meat could be eaten, if it needs to be processed (25), for example by heat or salt treatment (17), or if it shall be condemned totally, preserving people's and environment's health. At clandestine slaughterhouses, the animal health status is not identified (23).

In Brazil, even though the federal inspection registration of the food from animal sources was considered important by the interviewees in a city of Piauí state at the time of purchase, the carcasses do not go through any type of inspection. Due to lack of options, most interviewees buy pork meat in butchers with precarious hygienic conditions, in direct contact with microorganisms in the environment and objects, without any type of refrigeration, and at the end of the day, the meat goes to the freezer (12).

Animal welfare is an important issue that is being increasingly expanded in the world, but it still needs to be more divulged. In Mexico, people conveyed a high level of empathy with animal feelings and emotions; however, they clearly demanded more information and regulations related to farm animal welfare (4). The Mexican consumers mostly agree that animal welfare should be part of the teaching education programs in primary schools (4). Some Brazilians believe that pigs go through all kinds of discomfort during production and slaughter (12). Free-range chicken meat is preferred by Brazilian consumers (50.32%) when compared to caged chicken (36.13%), and people who buy chicken meat from the caged system do it because it has the lowest price (31.61%) (10). The preference for free-range chicken meat by 40.65% of the consumers was due to its appearance and by 23.23% because they think that it contains more nutrients than caged chicken meat (10).

If the animal is not well-treated and it does not have the five freedoms guaranteed, it is impossible to get good production and quality meat (10, 26). It could be endorsed as dark, firm, and dry (DFD) or pale, soft, and exudative (PSE) meat, which appears when animals are submitted to chronic or acute stress before slaughter, respectively (26, 27). However, many companies are still resistant to these standards, as they are associated with rising cost facilities and labor training, reflecting on the cost of the final product (10).

HUMAN HEALTH RISK

Food spoilage is different from food contamination (22). Spoiled foods are those that present changes in color, odor, flavor, and/or texture because they contain deteriorating microorganisms, being rejected by consumers (17, 22). Contaminated foods usually have pathogenic microorganisms, but the characteristics (color, odor, flavor, and texture) of the food are not altered and are naturally consumed (22). People will notice after consumption and usually present symptoms such as belly pain, vomiting, and diarrhea (22). Foodborne diseases can be much more serious than a short episode of gastroenteritis, with the possibility of residual (chronic) symptoms and the risk of death, especially in elderly and immunosuppressed patients (17). Thus, if the animal has a disease or if the food is not manufactured hygienically, pathogenic microorganisms may be present in the product and the consumer may acquire a disease. Still, food can be contaminated by physical hazards, such as nails, wood, and plastic, among others, or chemical hazards, such as detergents and pesticides, among others; however, all the hazards can be controlled by applying good manufacturing practices (22). In a research made in Mexico about consumers' perceptions and attitudes toward farm animal welfare and willingness to pay for welfare friendly meat products, they related that the three main risk factors associated with conventional animal foods were residues of antibiotics, hormones, and pathogens (4).

When the production of the food from animal sources is not carried out correctly or when it is illicit, the consumers' chances to acquire a foodborne disease are high, because the products that do not have adequate quality control are dangerous and harmful to human health. Among the most frequent diseases transmitted by food of animal origin are teniasis, brucellosis, tuberculosis, listeriosis, salmonellosis, toxoplasmosis, botulism, staphylococcal intoxication, hemolytic-uremic syndrome, campylobacteriosis, and diphyllobotriasis (15–17). It is estimated that 75% of emerging human diseases are zoonosis (28), and 20% of all human illnesses and deaths are associated with endemic zoonosis (2). Epidemics and even pandemics have their etiological agents linked to the consumption of food of animal origin, and although not yet confirmed, the coronavirus pandemic may have occurred due to the consumption of bat soup (15). In many circumstances, only a small number of people seek medical help, and not all are investigated. Even when the country has infrastructure for reporting data, only a small portion of foodborne diseases are reported to the authorities (17).

These diseases harm the economy of countries due to the work absenteeism, production and tourism decrease, and high expenses with hospitalizations and health treatments (2, 3, 17, 29). Foodborne diseases are a high economic burden (2).

FIGURE 2 | Environmental damage and bad hygienic conditions of a clandestine bovine slaughter (31).

According to the US Food and Drug Administration, foodborne illnesses have a total economic impact of 5 to 17 billion dollars (17). But why is the habit of consuming food from animal sources with good hygienic-sanitary control still not taken as seriously as it should be? How much is the consumer willing to pay or lose to obtain food safety?

ENVIRONMENT RISK

To produce food whose raw material is an animal, the treatment and correct disposal of residues must be considered so that they do not harm and pollute the environment (19, 30). When a product is clandestine, the producers do not care about the environmental preservation; for example, the blood and the rest of the carcasses are exposed to the environment, causing the presence of synanthropic animals and contamination of the soil, rivers, and groundwater (23).

In addition, in illicit slaughter the animal stays in an open place, under environmental temperature, with the presence of other animals such as carnivorous birds and dogs (**Figure 2**) that lick the carcass during the slaughter or feed on the remains of the carcass (23) and can be infected if the slaughtered animal is sick. The contact of the blood of a sick animal with open wounds or mucous membranes of the slaughterers who perform the slaughter also propitiate the spread of zoonosis, particularly the ones considered as neglected zoonosis associated with infrastructure problems and low socioeconomic status (32).

DISCUSSION

Safe foods are those that do not contain harmful agents or substances in quantities that may cause health problems or damage to the consumer; in other words, they are those that do not offer health hazards and guarantee the consumer's integrity (17). For this, it is necessary to have a systematic and proactive approach that minimizes food contamination from the farm to the fork (2, 5).

Correct food handling is essential to avoiding contamination by microorganisms (16, 22), and knowledge about the production of food of animal origin is essential for the consumers to choose quality and safe products for consumption (33), ensuring the preservation of their own health and the environment that they live. Many people think that it is enough to cook the food or to look for fresh food that is not dangerous and does not damage their health (16). During the cooking process, while vegetative microorganism cells are killed, the spores produced by some microorganisms, such as *Bacillus cereus* and *Clostridium perfringens*, can survive (17).

Have the consumers ever wondered which their responsibilities are when buying and/or consuming food? What their role would be in the sale of inspected animal products and in the reduction or extinction of the commercialization of clandestine products? The price of clandestine products is usually cheaper, but the products do not have the same quality as manufactured products within legal standards (33), for example, the comparison between choosing a clandestine and an inspected animal-origin product to the acquisition between a false and an original electronic product. It is a similar situation because the consumer's choice will depend on their knowledge about the factors that are linked to the production.

Moreover, it will depend on the consumer's interest in knowing how that product is being manufactured, especially about the quality of the raw material that makes it up, the production processes, the work conditions, and the damage caused to the environment. It should consider not only the assessment of risks but also technical possibilities, consumers' attitude/behaviors, and cost–benefit analysis (2). Are the production costs similar? The knowledge of the production factors and a brief analysis of the costs (19) and the work conditions, carried out in an ethical manner, would certainly help the consumers to choose the best option to purchase safe food.

The lack of consumers' awareness is a big problem (16, 17), because consumers are vulnerable to receiving any type of information, including false information (fake news) that is destructive in all areas, as it distorts what is real, it is easily and quickly spread on social media, and it gains great repercussions. For example, in Brazil, there is a myth that the color of the eggshell is related to good or bad nutrition contents and some people do not eat chicken meat because they believe that it contains hormones and antibiotics, so low consumption of both meat and eggs is associated with false information about poultry feed and the production system (6, 10).

The consumption of pork meat among Brazilians is still low and mostly linked to preconception due to lack of information about the change in Brazilian pig farming and for believing that pork has a high fat content and that it is bad for health (12). In an inquiry about the key aspects considered by consumers in the purchase and consumption of pork in Piauí/Brazil, 74% of the interviewees answered that pork has the highest level of disease transmission (12). The lack of information is also the biggest barrier to the acquisition and consumption of products in terms of wellbeing (12).

The power that digital influencers have on the consumers' lives, especially those of the Z generation, is enormous (11, 34), because they only indicate a product and the people who follow them will buy it, believing in their theories that have no scientific meaning or without making a good reflection. Some people may decrease or stop eating meat (10) and acquire anemia due to the misinformation transmitted by the influencers, as they often believe that animals feel pain when slaughtered, but do not even know what animal stunning is. For example, in Brazil, it was observed that the consumption of pork meat is popular, but it is still not highly or frequently preferred, which may be linked to the myths related to the product, and this consumption may even increase with the proper clarification of the main issues, fat content and sanitary preparations (12). Therefore, greater enlightenment is necessary for the awareness of the population, and the change requires investments in marketing, which encompasses the entire meat production chain, demystifying the negative image aggregated from its production to consumption.

The lack of consumers' knowledge affects the economy and people's lives, because when there is no awareness about the existence of potential problems with food, consumers end up eating a significant amount of contaminated food and become ill (17). In addition, clandestine slaughter favors the theft of domestic animals and the extinction of wild animals. In many developing countries, hunting and the consumption of meat from wild animals are also common cultural practices and increase the risk of zoonotic transmission (28). In Brazil, the sale and consumption of shark meat in the Amazon region will expose consumers to potentially harmful levels of inorganic arsenic (iAs) and mercury (Hg), as well as contribute to the population decline of species including those that are currently categorized as threatened (8). Therefore, it is important to know better the consumers' perception about food safety, because it can influence, along with other socioeconomic and demographic variables, the choice of food to be consumed and contribute to the effectiveness of the legislation to be implemented (6).

The low or absent surveillance in production and commercialization of food from animal sources is also a huge problem; however, there will never be enough inspectors if the consumers continue with the same buying and consuming habits. At this point, it is important to raise more questions to reflect on, such as the following: Is fake news or the lack of trade supervision of these products so important if the consumers obtained the necessary knowledge and changed their consumption behaviors? Why is there a commercialization of clandestine animal products? How much do foodborne diseases cost for the public coffers?

The economic basis is the law of supply and demand (35), so if consumers are aware of the scientific knowledge that the food of animal origin they are going to buy can endanger people's health, they would certainly not make the purchase of it, and naturally, they would report the place of sale to the competent authorities, hence facilitating their work and having no need to hire an enormous number of inspectors or increase the surveillance at production and commercialization. Even so, there would be a decrease in the supply of clandestine animal products. For it to happen, it is necessary to implant knowledge through health education of the population and, thus, to modify cultural and old behaviors, because when they are rooted, they are exceedingly difficult to be modified.

In underdeveloped countries, like Brazil, people, especially the older ones, say that the situation of consumption of food of animal origin has always been the same and that no one ever died from eating clandestine products, creating the popular saying "what does not kill, makes you fat." Another popular thought among people is that the consumption of these products can cause only a belly pain (referring to diarrhea), due to the lack of information about foodborne diseases.

In 2025, more than one billion people in the world will be elderly and more than two-thirds of them will live in developing countries (17). Population growth means an increased risk of foodborne illness, and it is not surprising that, in some countries, one in four people is at risk of contracting a foodborne disease (17). In the Caribbean region, despite undertaking limited surveillance on foodborne diseases, records related to bacterial foodborne zoonoses in food-producing animals and their associated epidemiological significance are poorly documented, giving rise to concerns about the importance of the livestock, food animal product sectors, and consumption patterns (2). It is recognized and pointed toward the relevance of pursuing a holistic One Health approach, with interdisciplinary engagement (2).

According to the World Health Organization (WHO), One Health is "an approach to designing and implementing programs, policies, legislation and research in which multiple sectors, communicate and work together to achieve better public health outcomes" (36). According to the United Nations Food and Agriculture Organization (FAO), the World Organization for Animal Health (OIE), or the Centers for Disease Control and Prevention (CDC), health outcomes depend on food safety, control of zoonoses, and combating antibiotic resistance while recognizing the interconnection between people, animals, plants, and their shared environment (36). The One Health concept has been extended beyond public health to include the ecological and environmental dynamics of disease in system-based frameworks such as Planetary Health and Eco-Health (36).

In summary, it is not enough for only inspection to be made in the animals and carcasses at slaughterhouses as well as surveillance in food sale, if there are still uninformed people who buy illegal or manufactured products without good hygienic-sanitary conditions. In the food chain, the production of safe food is everyone's responsibility (17). The moment the consumers know more, they will also be able to demand more quality and will become supervisors as well, for the benefit of their own health.

For this, education on health of the population is urgent and necessary to change the consumers' behaviors (2, 3), especially for children, so they can grow up with this knowledge, changing the old population's cultural habits and creating a future with roots fixed in scientific knowledge. In this way, foodborne diseases, which are underreported and neglected in underdeveloped countries (2), could be prevented and would support the world's economy. Global food safety is a shared responsibility.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

REFERENCES

1. Ritchie H, Roser M. *OurWorldInData.org. Meat and Dairy Production* (2017). Available online at: https://ourworldindata.org/meat-production#meat-consumption-tends-to-rise-as-we-get-richer (accessed December 03, 2020).
2. Guerra MMM, Almeida AM, Willingham AL. An overview of food safety and bacterial foodborne zoonoses in food production animals in the Caribbean region. *Trop Anim Health Prod.* (2016) 48:1095–108. doi: 10.1007/s11250-016-1082-x
3. Souza CP. The impact of food manufacturing practices on food borne diseases. *Braz Arch Biol Technol.* (2008) 51:815–23. doi: 10.1590/S1516-89132008000400020
4. Santana JCS, Souza MFS, Santos LPS, Dantas FC, Ferreira ACD, Gurgel ALC. Profile of professionals involved in slaughter and meat consumers in Itabi/SE. *Res Soc Dev.* (2020) 9:1–14. doi: 10.33448/rsd-v9i3.2544
5. Lama GCM, Estévez-Moreno LX, Sepúlveda WS, Estrada-Chavero MC, Rayas-Amor AA, Villarroel M, et al. Mexican consumers' perceptions and attitudes towards farm animal welfare and willingness to pay for welfare friendly meat products. *Meat Sci.* (2017) 125:106–13. doi: 10.1016/j.meatsci.2016.12.001
6. Andrade JC, Deliza R, Yamada EA, Galvão MTEL, Frewer LJ, Beraquet NJ. Percepção do consumidor frente aos riscos associados aos alimentos, sua segurança e rastreabilidade. *Braz J Food Technol.* (2013) 16:184–91. doi: 10.1590/S1981-67232013005000023
7. Brusa V, Costa M, Padola NL, Etcheverría A, Sampedro F, Fernandez PS, et al. Quantitative risk assessment of haemolytic uremic syndrome associated with beef consumption in Argentina. *PLoS One.* (2020) 15:1–32. doi: 10.1371/journal.pone.0242317
8. Souza-Araujo J, Souza-Junior OG, Guimarães-Costa A, Hussey NE, Lima MO, Giarrizzo T. The consumption of shark meat in the Amazon region and its implications for human health and the marine ecosystem. *Chemsph.* (2021) 265:129–32. doi: 10.1016/j.chemosphere.2020.129132
9. Berkhoff J, Alavarado-Gilis C, Keim JP, Alcade JA, Vargas-Bello-Pérez E, Gandarillas M. Consumer preferences and sensory characteristics of eggs from family farms. *Poultry Sci.* (2020) 99:6239–46. doi: 10.1016/j.psj.2020.06.064
10. Mendes LJ, Almeida Moura MM, Maciel MP, Reis ST, Silva, VG, et al. Perfil do consumidor de ovos e carne de frango do município de Janaúba-MG. *Ars Vet.* (2016) 32:81–7. doi: 10.15361/2175-0106.2016v32n1p%25p
11. Wielki J. Analysis of the role of digital influencers and their impact on the functioning of the contemporary on-line promotional system and its sustainable development. *Sustainability.* (2020) 12:1–20 doi: 10.3390/su12177138
12. Oliveira AP, Silva CP, Santana HA Jr, Santos MS, Britto JM, Mendes FBL, et al. Principais aspectos considerados por consumidores na aquisição e consumo de carne suína em colônia do Piauí. *Arq Ciênc Vet Zool UNIPAR.* (2017) 20:71–7. doi: 10.25110/arqvet.v20i2.2017.5810
13. Révillion JP, Kapp C, Badejo MS, Dias VV. O mercado de alimentos vegetarianos e veganos: características e perspectivas. Cadernos Ciênc Tecnol. (2020) 37:e26603. doi: 10.35977/0104-1096.cct2020.v37.26603
14. Randle J, Metcalfe J, Webb H, Luckett JCA, Nerlich B, Vaughan N, et al. Impact of an educational intervention upon the hand hygiene compliance of children. *J Hosp Infect.* (2013) 85:220–5. doi: 10.1016/j.jhin.2013.07.013
15. Shirani K, Sheikhbahaei E, Torkpour Z, Nejad MG, Moghadas BK, Ghasemi M, et al. Narrative review of COVID-19: the new pandemic disease. *Iran J Med Sci.* (2020) 45:233–49. doi: 10.30476/ijms.2020.85869.1549
16. Collins JE. Impact of changing consumer lifestyles on the emergence/reemergence of foodborne pathogens. *Emerg Infect Dis.* (1997) 3:471–9. doi: 10.3201/eid0304.970409
17. Forsythe SJ. *Microbiologia da Segurança dos Alimentos*. Porto Alegre: Artmed (2013). 607p.
18. Fellows P. *Food Processing Technology, Principles and Practice*. Boca Raton, FL: CRC Press (2000). 575 p.
19. Vasconcellos MC, Pignatti MG, Pignati WA. Employment and occupational accidents in the slaughterhouse industry in expansion areas of agribusiness, Mato Grosso, Brasil. Saúde Soc. (2009) 18:662–72. doi: 10.1590/S0104-12902009000400010
20. Santana RF, Santos DM, Martinez ACC, Lima AS. Qualidade microbiológica de queijo-coalho comercializado em Aracaju, SE. *Arq Bras Med Vet Zootec.* (2008) 60:1517–22. doi: 10.1590/S0102-09352008000600031
21. Nespolo NM, Vedovelli M, Valmorbida MK, Almeida CC, Pizauro LJL, Pereira N, et al. *Microbiological Quality of "Coalho" Cheeses Commercialized in Aracaju - SE.* Anais do 13° Simpósio Latino Americano de Ciência de Alimentos (2019). Available online at: https://proceedings.science/slaca/slaca-2019/papers/microbiological-quality-of----coalho----cheeses-commercialized-in-aracaju-----se (accessed December 01, 2020).
22. Sebrae. *PAS - Programa Alimentos Seguros. FASCÍCULO 1. Segurança dos Alimentos Necessária Para Garantir a Saúde do Consumidor*. São Paulo: Garilli (2004). 18 p.
23. Magioli CA. *Abate Clandestino* (2017). Available online at: https://animalbusiness.com.br/colunas/inspecao-e-alimentos/abate-clandestino/ (accessed December 01, 2020).
24. Portal Correio. *Após Denúncia, Polícia Ambiental Desativa Matadouro Clandestino* (2017). Available online at: https://portalcorreio.com.br/apos-denuncia-policia-ambiental-desativa-matadouro-clandestino-em-jp/ (accessed December 01, 2020).
25. Wilson WG. *Wilson's Practical Meat Inspection*. Oxford: Blackwell Publishing (2005). 312 p.
26. Paranhos da Costa MJR, Sant'Anna AC. *Bem-Estar Animal Como Valor Agregado nas Cadeias Produtivas de Carnes*. Jaboticabal: Funep (2016). 107 p.
27. Grandin T. *Livestock Handling and Transport*. Wallingford: CAB International (2019). 520 p.
28. Food and Agriculture Organization of the United Nations. *Protecting People and Animals from Disease Threats* (2019). Available online at: http://www.fao.org/3/i8747en/I8747EN.pdf (accessed December 01, 2020).
29. Ferreira JAF. *Panorama das Doenças Transmitidas por Alimentos no Brasil Entre 2000 e 2015* (Master's Thesis) (2017). São Paulo: Universidade de São Paulo.
30. Surti HS. Physico-Chemical and Microbial Analysis of Waste Water from different Industry and Cod Reduction Treatment of Industrial Waste Water by using Selective Microorganisms. *Int J Curr Microbiol Appl Sci.* (2016) 5:707–17. doi: 10.20546/ijcmas.2016.506.077
31. Rota do Sertão. *Vigilância Sanitária e Polícia Civil Apreende Carne de Abate Clandestino na Zona Rural de Tucano-BA* (2014). Available online at: http://www.rotadosertao.com/noticia/43064-vigilancia-sanitaria-e-policia-

civil-apreende-carne-de-abate-clandestino-na-zona-rural-de-tucano-ba (accessed December 01, 2020).

32. Pellizzaro M, Martins CM, Yamakawa AC, Ferraz DC, Morikawa VM, Ferreira F, et al. Molecular detection of *Leptospira* spp. in rats as early spatial predictor for human disease in an endemic urban area. *PLoS One.* (2019) 14:e0216830. doi: 10.1371/journal.pone.0216830
33. Matos KMO, Ribeiro LA, Souza RA, Kobayashi PF. Perfil do consumidor de carne bovina das feiras livres de Aracaju, SE. *Hig Alim.* (2017) 31:27–32. doi: 10.37585/HA2021
34. Litterio A, Nantes E, Larrosa J, Gómez L. Marketing and social networks: A criterion for detecting opinion leaders. *Eur J Manag Bus Econ.* (2017) 26:347–66. doi: 10.1108/EJMBE-10-2017-020
35. Pindyck R, Rubinfeld D. *Microeconomia.* São Paulo: Pearson Education do Brasil (2013). 742 p.
36. Comizolli P, Lohan KMP, Muletz-Wolz C, Hassell J, Coyle B. The interconnected health initiative: a Smithsonian framework to extend one health research and education. *Front Vet Sci.* (2021) 8:629410. doi: 10.3389/fvets.2021.629410

Conflict of Interest: The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Public Health

ORIGINAL RESEARCH
published: 25 June 2021
doi: 10.3389/fpubh.2021.624574

Check for updates

Challenges of Rabies Surveillance in the Eastern Amazon: The Need of a One Health Approach to Predict Rabies Spillover

*Victor Bastos [1,2], Roberta Mota [1,2], Mylenna Guimarães [2], Yuri Richard [1], André Luis Lima [3], Alexandre Casseb [3], Gyovanna Corrêa Barata [4], Jorge Andrade [5] and Livia Medeiros Neves Casseb [2]**

[1] Federal University of Pará, Institute of Biological Sciences, Belém, Brazil, [2] Department of Arbovirology and Hemorrhagic Fevers, Evandro Chagas Institute, Ananindeua, Brazil, [3] Federal Rural University of the Amazon, Institute of Animal Health and Production, Belém, Brazil, [4] Amazon Metropolitan College, Belém, Brazil, [5] Pará State Health Secretary, Health Surveillance Directorate, Belém, Brazil

OPEN ACCESS

Edited by:
Laura H. Kahn,
Princeton University, United States

Reviewed by:
Maxine Anne Whittaker,
James Cook University, Australia
Thiravat Hemachudha,
Chulalongkorn University, Thailand

Correspondence:
Livia Medeiros Neves Casseb
alouattacaraya@yahoo.com.br

Specialty section:
This article was submitted to Planetary Health, a section of the journal Frontiers in Public Health

Received: *31 October 2020*
Accepted: *21 May 2021*
Published: *25 June 2021*

Citation:
Bastos V, Mota R, Guimarães M, Richard Y, Lima AL, Casseb A, Barata GC, Andrade J and Casseb LMN (2021) Challenges of Rabies Surveillance in the Eastern Amazon: The Need of a One Health Approach to Predict Rabies Spillover. Front. Public Health 9:624574. doi: 10.3389/fpubh.2021.624574

Brazil has been promoting essential improvements in health indicators by implementing free-access health programs, which successfully reduced the prevalence of neglected zoonosis in urban areas, such as rabies. Despite constant efforts from the authorities to monitor and control the disease, sylvatic rabies is a current issue in Amazon's communities. The inequalities among Amazon areas challenge the expansion of high-tech services and limit the implementation of active laboratory surveillance to effectively avoid outbreaks in human and non-human hosts, which also reproduces a panorama of vulnerability in risk communities. Because rabies is a preventable disease, the prevalence in the particular context of the Amazon area highlights the failure of surveillance strategies to predict spillovers and indicates the need to adapt the public policies to a "One Health" approach. Therefore, this work assesses the distribution of free care resources and facilities among Pará's regions in the oriental Amazon; and discusses the challenges of implanting One Health in the particular context of the territory. We indicate a much-needed strengthening of the sylvatic and urban surveillance networks to achieve the "Zero by 30" goal, which is inextricable from multilateral efforts to combat the progressive biome's degradation.

Keywords: universality, equity, Amazon, human rabies, One Health

INTRODUCTION

Brazil's seventh Constitution defined health services as a fundamental Brazilian right. This revolutionary and pioneering strategy, founded on social justice, sets up the basis for a public health system—Brazil's Unified Health System (SUS). The SUS was later regulated by law n° 8080/1990, which defines its principles: universality, equity, and integrity (1, 2). In summary, the system aims to guarantee free universal access to both essential care services and complex procedures such as surgeries to 140 million people throughout Brazil's territory (3). However, due to regional inequalities, ensuring those principles has been a challenge, especially in Amazon riverside communities that have been affected by neglected diseases (4).

The Brazilian Amazon composes about 49,3% of Brazil's area geographically and is distributed into nine states (5), which through law n° 291/1967 and law n° 356/1968, are divided into the Occidental and Oriental Amazon. The first division included four states, while the second division comprises five others, including Pará, in the country's northern region (6). These Amazonian states were developed unequally compared with Brazil's capitalist main poles, and its integration to International Trade started after the oil crises in 1973 initiated a disordered development process focused on limited economic spots (7) (p. 154) that strongly evoked social and territorial conflicts (8) (p. 46). This inequity is reflected by the low Human Development Index of all Amazonian states during the first decade of the 21st century (9), despite their international and national importance as a raw material provider.

Regarding the state of Pará, government strategies aiming to populate remote areas and develop its commercial activity during the 20th century created five different poles associated with mineral exploration, that are the center of Pará's Gross Domestic Product (7) (p. 157–159) (10) (p. 159). These economic strategies enhanced selective economic development, promoting regional, social, and economic inequities within different state areas related to mining and other activities (10, 11) (p. 158–164). It also started an intense human population growth, besides ecological transformation in the biome, which enhances human-wildlife interaction, and introduces communities to the cycle of wild pathogens, highlighting the importance of the One Health approach in the Amazon area (12–15).

One Health is a multisectoral and multidisciplinary approach that recognizes the close interaction between human and animal health (16). This approach is an essential tool for guiding the efforts of public policies in the prevention of zoonosis and has demonstrated efficient results toward the control of rabies in endemic areas (17). As such, there is a need for close and continuous vigilance of at-risk populations that demand cross-sector cooperation, including proactive surveillance of animal vectors such as dogs and bats, which play an essential role in the transmission of rabies.

Rabies is an acute infectious encephalitis caused by a neurotropic virus from the *Lyssavirus* genus, which can infect all mammalian hosts, leading to death in almost all cases. Its transmission to humans occurs mainly through a bite from an infected domestic or wild host (18, 19). Despite its preventable aspects, rabies threatens almost 60,000 humans globally, especially in Africa and Asia (20). In Brazil, the Rabies Prophylaxis Program (PNPR) achieved actual progress in the 21st century toward controlling urban rabies through post-exposure prophylaxis (PEP) schemes. However, rabies transmitted by bats is a current issue: from 2003 to 2018, 143 fatal cases mainly transmitted by wild vectors were reported. There was a high level of transmission in the state of Pará, the second highest endemic area in the country (4, 21–23). The groups most affected by rabies in the Amazon were those living in neglected zones, where equitable public health services are not available, emphasizing this illness's neglected profile (4, 20).

The occurrence of human rabies cases in neglected communities suggests the failure of surveillance strategies, and it indicates the need for improvements in the parameters of the public health system to achieve WHO's "zero by 30" goal. Therefore, the work aims to assess: (i) the distribution of health services from different levels in the context of rabies prevention and (ii) the challenges of implementing a "One Health" approach in the Amazon.

MATERIALS AND METHODS

Data Collection

A descriptive, observational, and cross-sectional research was carried out to assess data on the sufficiency of free essential care resources available to assist risk communities in Pará zones from 2018 to 2019. We collated (i) the distribution of health units based on their complexity levels; (ii) surveillance data on domestic and wildlife animal-bite reported during the period, (iii) availability of human rabies vaccine; and (iv) the distribution of health centers for diagnosis. Data about both health units and the availability of rabies vaccines are public-access and can be formally requested from the State Health Secretary of Pará (SESPA) by every health professional through the institutional e-mail (protocolo@sespa.pa.gov.b). The request was processed as PAE 2020/434223 and accepted on June 25, 2020. We obtained surveillance data on animal bites from the "Individual Investigation Reports of Human anti-Rabies Care" form filled by health workers at health units and submitted to SINAN (24).

This document must be completed by nurses and other health professionals each time a patient seeks care after animal aggression, and it is sent weekly from municipalities to state levels and biweekly to the Health Ministry (MS). They are obligated to investigate and finalize cases within 2 months. The investigations may follow PEP administration depending on the type of injury and monitoring the potential rabid dog; upon direct contact with a sylvatic animal, the patient receives five doses of intradermal rabies vaccine (cell culture) on days 0, 3, 7, 14, and 28 (25). It is concluded when the patient interrupts the treatment or when PEP finishes.

This work assessed the total applied doses of only human rabies vaccines (cell culture/Vero and cell culture/embryo) and the animal bite reports on SINAN in the whole state from 2018 to 2019. The data unavailability on the type of doses (1st dose, 2nd, 3rd, four, or booster), and the absence of the profile of animal bite reported from the municipalities limits the article's conclusions.

In order to analyze the distribution of free care resources among the different zones in Pará, we compiled health unit information based on their level (**Figure 1**), following the Primary attention, Second and Third attention (26). This division is based on health services' organizational arrangements from different technological levels, which through integrated collaboration, seek to guarantee free care services.

Study Area

This study covered the state of Pará, located in the north of Brazil, to the Oriental Amazon (6). The state area is about 1,245,870,707 km² and has an estimated population of 8,690,745 people (5).

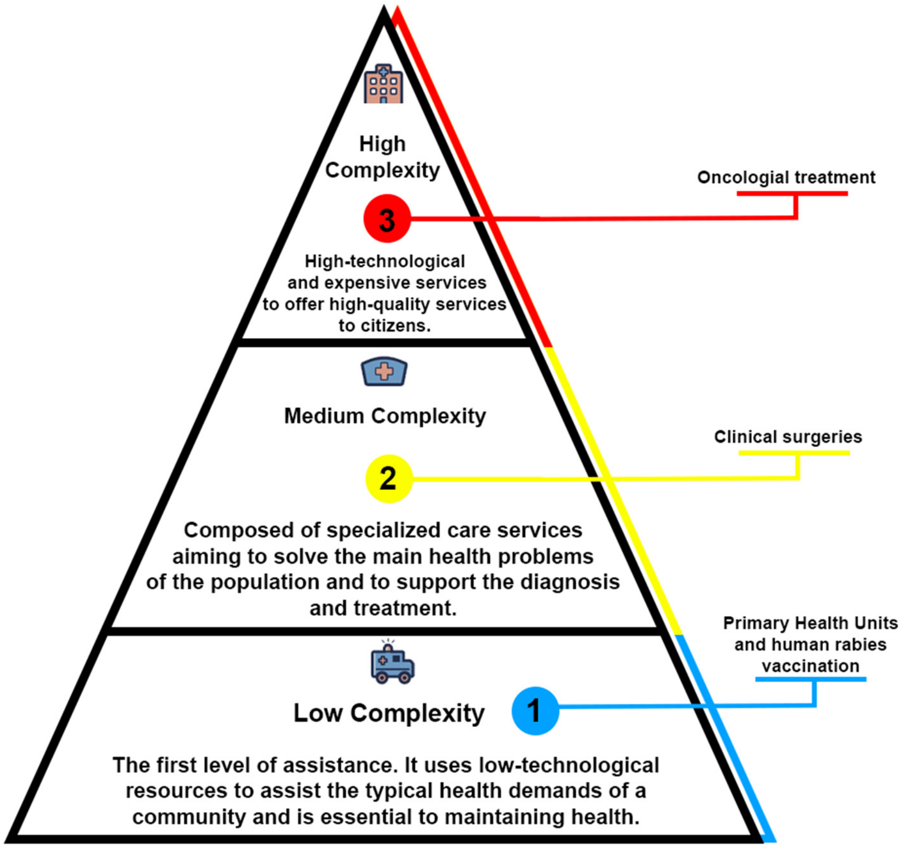

FIGURE 1 | The levels of health care in the context of Brazil's system. The organizational health system's model follows the WHO's recommendations to divide levels of assistance according to health units' resources available to meet the patient's demands. The primary level works in a preventable approach by promoting close contact with the community. It may also offer free access to vaccines and medicine. The second level comprises hospitals and care centers that provide ambulatorial assistance to solve the main health problems. The third level offers high-cost and high-specialized treatments for the patient's rehabilitation, including Intensive Care Units and oncologic treatment.

The analysis followed data available from the municipalities arranged in the 13 Health Regions, which SESPA defined according to the Resolution CIB/PA n° 90, from June 12, 2013: Araguaia, Baixo Amazonas, Carajás, Lago de Tucuruí, Marajó I, Marajó II, Metropolitana I, Metropolitana II, Metropolitana III, Rio Caetés, Tapajós, Tocantins e Xingú, covering 144 municipalities (**Figure 2**).

This administrative division aims to improve the distribution of free medical resources among the municipalities and provide equal access to free care services. The division also considers the neighboring areas' geographical and demographic aspects to include them in the same health region.

Epidemiological Data

The data on human rabies epidemiological status in Brazil is open access and is available on the Datasus tabnet platform (http://www2.datasus.gov.br/DATASUS/index.php). This database collects, organizes, and offers Brazil's health information, including epidemiological data on infectious diseases; in which human rabies is inserted.

Statistical Analysis

We performed a descriptive analysis of the distribution of primary care units, rabies vaccines, and medium and high-level hospitals by calculating the differences in the rate per 10^4 people or 10^5 inhabitants. The regional rate of medical services was determined by the ratio of total health units and regional population per 10,000 or 100,000 inhabitants.

$$rate = \left(\frac{total\ of\ health\ units}{regional\ population}\right) x\ 10,000\ or\ 100,000 \qquad (1)$$

Statistical analysis was performed with Graph Pad Prism 8th version for Windows 10. The mean human rabies' offer compared to the total of animal-bite notification by Wilcoxon Signed Rank Test to assess the availability of free medical resources among the regions. We performed a One-way ANOVA to analyze the efficiency of the PEP scheme by comparing the mean of concluded and non-concluded treatments with the total notifications.

The differences were considered significant at a 95% confidence interval ($p < 0.05$).

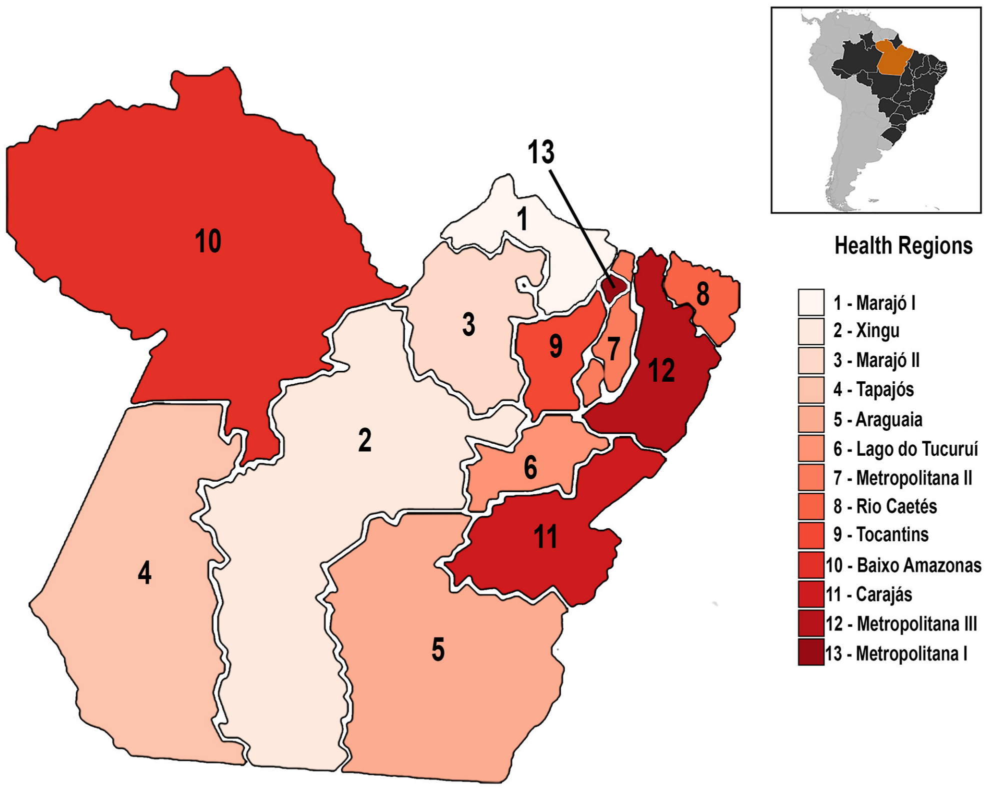

FIGURE 2 | Pará's administrative division (SESPA). The regionalization of care resources is a national effort to reduce health inequities among Brazil's regions. In the Pará state, there are 13 health regions, which comprise the 144 municipalities of the area, considering their geographical characteristics.

Populational Data

Data on the Brazilian states' and municipalities' population is public access information, and it is available on the website of IBGE (https://cidades.ibge.gov.br/). The complete sociodemographic information of every Brazilian area can be accessed by searching the state and the cities' names on the website. To perform the analysis on the distribution of health services according to their levels per 10^4 or 10^5 inhabitants, we add each municipalities' population to estimate the total inhabitants of each health region.

RESULTS

The Distribution of Primary Care Units Among the Health Regions of Pará State

According to Brazil's Health Ministry's recommendation, the primary health units should assist an area of 12–18 thousand inhabitants in big cities, depending on the services offered to the community (Ministério da Saúde). Thus, when we assessed the distribution among Pará's area, we observed a homogenous distribution of these units among the state's areas, varying from 1 primary health unit/10^4 inhabitants to 4 primary health units/10^4 inhabitants (**Table 1**). The riverine area, Marajó I (4,3/10,000), has the most significant distribution of primary health care units, followed by Tapajós (4,3/10,000) and Rio Caetés (4,2/10,000). In contrast, the Metropolitana I region (0.9/10,000), which concentrates the biggest population among the areas, had the lowest distribution, almost three times lesser than Marajó I and Tapajós.

Differential Availability of Specialized Medical Resources and the Concentration of High-Tech Resources in Urban Centers

The availability of specialized care services provided by hospitals and emergencies from medium and high technological-level greatly varied per 100,000 people among the health regions (**Figure 3A**). Neglected areas, such as Marajó I (1,6/100,000) and Marajó II (5/100,000), had the worst indicators, followed by Metropolitana II (9,7/100,000). The greatest indicators were concentrated in a few urban areas, such as Carajás (63/100,000) and Metropolitana I (55/100,000)—which respectively concentrate 39 and 34 times more hospitals than Marajó I.

Among the health regions, the Metropolitana I region concentrates the only laboratory which supports animal and human rabies antemortem and postmortem diagnosis in the Amazonia, the Instituto Evandro Chagas, located at Ananindeua city (1° 21′ 59″ S, 48° 22′ 20″ W). Besides supporting Pará's demand, the laboratory has a central role in supporting rabies surveillance in the North area of the country.

TABLE 1 | The distribution of primary health units among Pará's regions.

Health regions (SESPA)	Total of primary health units	Distribution/10^4 inhabitants	Regional population (2019)
Araguaia	194	3.42/10^4 people	566,682
Baixo Amazonas	252	3.26/10^4 people	771,715
Carajás	204	2.33/10^4 people	875,232
Lago de Tucuruí	116	2.51/10^4 people	461,593
Metropolitana I	205	0.91/10^4 people	2,238,680
Metropolitana II	142	3.86/10^4 people	367,592
Metropolitana III	375	3.99/10^4 people	939,421
Rio Caetés	231	4.26/10^4 people	541,251
Tapajós	97	4.38/10^4 people	221,135
Tocantins	193	2.73/10^4 people	705,089
Xingú	134	3.82/10^4 people	350,276
Marajó I	105	4.30/10^4 people	244,027
Marajó II	115	3.59/10^4 people	320,172

The analysis on the mean coverage of services from the Primary Health Care (PHC) indicates a homogeneous distribution among the areas. It considered data on the availability of Family Health Support Center (CASF), primary health units, health center, home care, indigenous health care units, and fluvial mobile units.

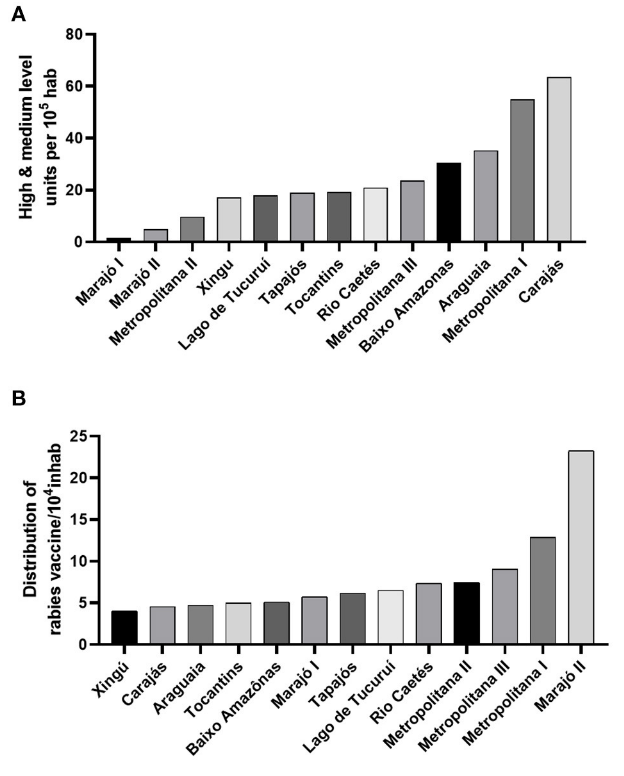

FIGURE 3 | The availability of free medical resources and facilities. **(A)** human rabies vaccine's distribution per 10,000 people is heterogeneous and limited in some areas of the state. **(B)** the coverage of hospitals from medium and high-technological resources is concentrated in a few areas of the territory, and almost absent in neglected communities.

The Offer of Cell Culture Human Rabies Vaccines

Rabies prophylaxis may be administered in two primary schemes: Post-Exposure Prophylaxis (PEP) and Pre-Exposure Prophylaxis (PrEP) by applying intradermal doses of human rabies vaccine raised in cell culture (27). Among Pará's regions, the availability of this resource in the health units varied from 4 vaccines/10,000 people—such as in the Araguaia (4,69/10,000), Carajás (4,55/10,000) and Xingú (4,02/10,000) -, to 23/10,000 people in the Marajó II areas (**Figure 3B**).

The total average of the doses available in the regions was compared with the total average of animal-bite notifications in SINAN. Our data indicate that the availability of human rabies vaccines may be insufficient to assist the local demands (**Figure 4A**).

Reports on Animal-Bite Assistance and PEP Administering in the Pará Areas

In 2018, there were 33, 549 cases of wild and domestic animal bite-notifications reported in the SINAN database, of which 17,029 patients (50,7%) did not finish the treatment without interruptions. In 2019, there were 30,970 notifications of animal injury, in which 18,163 (58%) did not follow the complete PEP scheme. The differences between concluded and non-concluded PEP were both considered significant ($p < 0.05$) to the total average of notifications (**Figure 4B**).

The Epidemiological Profile of Rabies in the Amazonia: Central Role of the State of Pará in Human Rabies Epidemiology

In Brazil, 160 fatal cases of human rabies were reported from 2001 to 2018, in which 58 cases (36%) have occurred in the North (**Figure 5**). Most of the cases that occurred in the northern region were reported in the state of Pará, which totaled 47 cases (81%) of rabies, occurred in 2001 and 2002, in the Carajás region (three cases); in 2004, in the Metropolitana I (two cases), Rio Caetés (three cases), and Marajó II (15 cases). In 2005, 14 cases were reported among Metropolitana I (eight cases) and Rio Caetés (six cases). More recently, a bat-transmitted rabies outbreak was reported in the Marajó II region, which confirmed ten fatal cases.

DISCUSSION

Brazil has achieved improvements in health indicators by implementing and expanding free healthcare programs, in which Primary Health Care (PHC) are the protagonists (28). PHC, mainly represented by primary health units, considers the socio-cultural aspects of the area coverage to promote community and family orientation by health educational strategies in a close-contact approach and plays an essential role in promoting health, especially in the pandemic's context (29). Similarly, some health programs, such as the national rabies prophylaxis program, have contributed significantly to reducing human mortality through dog and cat vaccination campaigns, besides implementing pre-exposure prophylaxis (PrEP) and post-exposure prophylaxis (PEP) strategies. Despite Brazil's efforts toward controlling

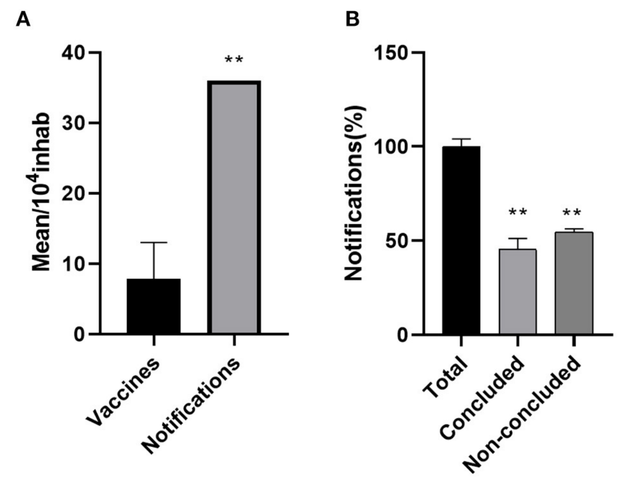

FIGURE 4 | Reports on animal bite and PEP administration in the Pará state during 2018 and 2019. **(A)** the offer of rabies vaccines may be insufficient to assist the PEP demand in some neglected areas of the state **(p < 0.01). **(B)** the reports on patients seeking care after a sylvatic or domestic animal bite indicate the high rate of interruption in the PEP **(p < 0.01).

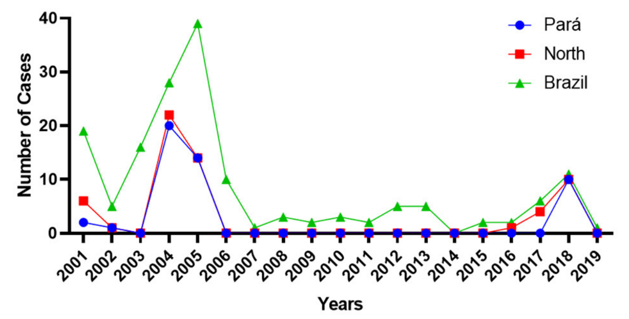

FIGURE 5 | Human rabies epidemiology in northern Brazil (2000–2018). It was reported 160 fatal cases in the period, with bat-transmitted outbreaks. Pará state has a central role in the northern region, representing 81% of the total confirmed cases.

urban rabies and achieving "Zero by 30" WHO's goal, rabies transmitted by wild vectors, such as bats, are also a current issue in the Amazon areas (30). Rabies reemergence in neglected communities has a close relation with anthropic destruction of animals' habitats and health, affecting disease transmission dynamics (13, 15, 31, 32). The occurrence of a bat-transmitted human rabies outbreak in 2018 at Melgaço's riverside areas and throughout other Amazon areas suggests a failure of rabies surveillance and health systems to deal with rabies considering the availability of preventable strategies to avoid the occurrence in animals and humans.

Therefore, this work assessed the distribution of free care services and resources among Pará's health regions. Health and socioeconomic inequities are challenges to achieving the universality of health policies and are aggravated by the limited governance of health authorities in neglected areas, particularly in the Northern region (33). Health services' regionalization may serve as an alternative to reduce inequities in free care services access (34). Unlike Andrade et al. (14), and Garnelo et al. (35) that discuss the limited PHC's distribution in the Amazon areas, in the particular context of the state of Pará, we demonstrated a homogeneous distribution of primary health units and primary health care centers among the regions of Pará. However, this data may not reflect the reality of these municipalities since we could not assess this distribution within their context, but at the regional level, limiting the analysis of particular distribution in remote areas. Although there were no discrepancies in the coverage of health units among the areas of Pará, other variables, such as the distribution of health professionals in urban and rural areas, may influence the quality and offer of essential care services, impacting the correct guidance treatment of aggravations in remote zones. That is because the northern region, including the capitals, has the worst indicators of distribution of doctors per thousand inhabitants among Brazil's regions (36). This indicates a panorama of greater vulnerability, with difficulties in access to physicians. However, health inequalities cannot be analyzed only by focusing on the PHC but also by considering other levels (medium and high) of health assistance (37).

Moreover, the limitation of the high-technological service in the particular Amazon scenario is a historical issue. The progress in reducing poverty and inequality in the 2000s had a paradoxical effect on Brazilian territory since the developmental agenda focused on activities related to the geographical specificities of the macro-regions contributing to spatial inequalities (38). This strategy enhanced the social conflicts in the area (8), and reproduced the same pattern in the mesoregions of Pará (7). Initially, it also affected the distribution of health services in remote zones: health services from the medium and high level remained concentrated in few developed areas (39), differently from the distribution of primary health units—that was significantly expanded in the poorest regions of the country, with greater limitations for its implementation in densest metropolitan peripheries, similarly to our results (**Table 1**). Despite Brazil's efforts to reduce vulnerability in recent decades, current data still demonstrate a concentration of these specialized health services (40). There is a considerable difference in the mean-coverage of hospitals of medium and high-level complexity among rural and urban areas of the Pará: the availability of specialized medical resources is almost 35 times greater in Metropolitana I (54.9/100,000) than Marajó I (1.6/100,000), and 11 times greater than Marajó II (4.9/100,000), affecting the access of neglected communities to specialized care resources. The unequal distribution of medical resources indicates the need for a large displacement between the regions to seek medical assistance, which directly influences the time for receiving adequate treatment in case of accidents; and compromises the maintenance of a patient's life. However, from other urban areas, riverside communities have particular barriers in transporting to the nearest hospital since it may be influenced by the hydrological cycles of drought and flooding, besides climatic conditions (35). Based on this scenario, in 2017, Brazilian authorities implemented the Fluvial mobile units (FMU) aiming to guarantee integrated health assistance to these communities (41). However, it could not meet more complex demands such as hospitalizations, the treatment, and diagnosis of infectious diseases, such as human rabies.

Regarding rabies diagnosis, the WHO indicates that the laboratory should be involved beyond human and animal diagnostic, maintaining a proactive role in the investigation, planning, and assessment of rabies cases using a One Health approach (42). Successful strategies in Latin America toward rabies control are based on dog-maintained RABV monitoring molecular sequencing, phylogenetic analysis, and antigenic typing to provide information on viral variants or lineages linked with its reservoir hosts—that is useful to mapping risk areas and help to implement surveillance strategies (43). The governments must also provide funding to implement decentralized networks for rabies surveillance and prevention, responsible for collecting samples to submit to specialized laboratories on the diagnosis, and the laboratories should work in a decentralized-network manner to support wild and human monitoring to expedite local strategies toward control and prevention (44).

For example, In Nepal, a coordinated approach implemented a laboratory network with five regional laboratories located in critical areas. It has been successfully typing and identifying the disease's epidemiological profile, which guides the implementation of preventable strategies. However, in the context of the Amazon, the limited distribution of laboratories working on animals' support (postmortem) and humans (ante- and postmortem) diagnosis represents a challenge to both rabies monitoring in the region and human rabies management, since a patient with rabies requires a complex structure, with an intensive care unit, and constant laboratory monitoring (45). The centralized laboratory networking may widely affect rabies surveillance by impacting the time in which results can be delivered and consequently delaying the health system's response to the risk of exposing naive hosts to the virus. The identification of positive cases needs a quick data reporting scheme for rapid decision-making (46), and a rapid animal's diagnosis with phylogenetic analysis may also affect the need for human post-exposure prophylaxis administration since the effective identification of risk zones can guide the implementation of preventable strategies, such as PrEP administration.

It would be interesting that emerging-endemic neighboring countries in Latin America, such as Brazil, Peru, and Bolivia, outline multilateral efforts to finance new epidemiological monitoring networks. It should also include sharing technological tools for the diagnosis, prevention, genetic, and serological typing to identify, guide, and perform strategies directed at areas of greater risk of spillover, especially in Amazon neglected zones. This international networking is already established in Europe (47), by the Middle East and Eastern Europe Rabies Expert Bureau (MEEREB), and in the Northern hemisphere, by Canada, United States, and Mexico through the North American Rabies Management Plan (NARMP) (48), which successfully achieved the control in endemic zones (49). It is noteworthy that monitoring rabies in the Amazon has beyond social but also economic importance since bovine livestock production has substantially increased throughout the decades, and the increase of cattle communities is related to the greater risk of human and animal exposure to RABV (50), especially in zones related to extensive deforested areas, large herds of cattle, and the presence of highways (51).

Similarly, the availability of essential resources, such as human rabies vaccines (**Figure 4A**), may not be satisfactory to meet the populational demands in some areas, especially in Carajás, Xingú, and Araguaia, which had the lowest distribution among the other regions (**Figure 4B**). Under the PEP plan, an animal bite may require an intradermal administration of cell-culture vaccines (27), and the patient must immediately seek medical assistance at a primary health unit or emergency center for receiving the correct PEP. Depending on the severity of the injury or the animal's aggressive characteristics (52), the treatment may be followed by RIG's administration (53). However, the long-term aspect of rabies prophylaxis, which involves multiple vaccine administrations at different times (27), and the low availability or the centralization of essential resources in some health units, can affect the efficiency of PEP. In addition to health inequities, geographic, cultural, and social aspects must be considered and may reflect low treatment continuity. For example, the insufficiency of knowledge about rabies in remote Amazon areas may play an important role in seeking care after an animal bite injury (54). Together, these aspects might explain the differences shown in **Figure 5**, which indicate that only half of the patients concluded the vaccination plan Nevertheless, the challenges of correctly following the PEP and guaranteeing essential resources are not a restricted issue in just the Amazonian reality but also a general context. Appropriate PEP use was also limited in China (55), India (56), and in other countries of Asia and Africa, in which the high cost and limited availability of the vaccine are the main barriers to receiving the correct PEP (57).

It highlights the importance of international efforts to reallocate resources to produce and distribute essential health supplies to vulnerable areas since well-succeeded countries have widespread access to rabies vaccines and control of rabies (57). Administering PrEP in at-risk communities in Latin America must be considered since it is an efficient strategy adopted in Peru and other countries (58). It has a cost-effective aspect, which may reduce the need for PEP with vaccination schemes. These efforts must be accompanied by extensive animal vaccination campaigns, including livestock vaccination, with the monitoring of animal herd immunity, followed by the control of cat and dog populations. Simple initiatives, such as promoting ample health education campaigns, may effectively reduce non-conformities on PEP administration and help expand the populational adherence to the animal's campaigns.

Endemic and emerging countries should also be proactive in mapping and monitoring health inequities (59) to implement public policies in at-risk areas. In the particular context of the neglected Amazonian areas, health policies need to embrace resource distribution and promote access to health services opportunities (60, 61), considering the socio-cultural heterogeneity and the geographic aspect of the territory (62). The heterogeneous distribution of high-tech biomedical resources among these highly diverse zones and the limited laboratory network denotes a barrier to the implementation of a proactive

"One Health" approach in the Amazonian context since it requires constant animal, human, and vector surveillance (17), which become complex with an insufficient laboratory network. This active monitoring has been efficient in predicting and detecting the circulation of RABLV strains in the Ceará state (24), and the surveillance and control of sylvatic rabies is a crucial strategy in North America (63). These barriers may be overcome in the long-term if strategies that involve multilateral efforts between the different sectors of the government, states, and municipalities strengthen and establish new decentralized monitoring networks in different areas of the Brazilian territory. This can contribute to a positive outcome not only in the context of rabies but also in the prediction of emerging and reemerging infectious diseases in the Brazilian Amazon (12).

Therefore, this paper indicates a must-needed improvement in the health indicators and surveillance strategies in rabies reemergence, mainly in the particular scenario of the Amazon, since there are inequities in access to rabies treatment and vaccines in the neglected areas of the state. These rabies-based inequities are due to both poor access to health services in these communities, and the environmental exploitation that present government policies have which increased the contact of naïve hosts to wild vectors. Thus, to control human rabies in endemic areas and help achieve the "zero by 30" WHO goal, it is essential that Brazil's government promotes equitable policies and play a proactive role in monitoring RABLV circulation. Therefore, these efforts also require a constant commitment by public entities to protect the Amazon biome in its entirety, which is inextricable of animal's and human health.

DATA AVAILABILITY STATEMENT

The original contributions generated for this study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

VB, AC, and LC idealized and designed the research. VB draft the paper. VB, AL, and YR made the images. VB, MG, YR, AL, RM, GB, and JA analyzed and processed the data. VB and YR performed the statistics. VB, RM, and AL edited the paper. All the authors have reviewed and accepted the submitted manuscript version.

ACKNOWLEDGMENTS

We thank Pará State Health Secretary (SESPA), particularly represented by Jorge Andrade, for the essential support and contribution given, making this research possible.

REFERENCES

1. Casa Civil. *L8080*. (1990). Available online at: http://www.planalto.gov.br/ccivil_03/leis/l8080.htm (accessed June 19, 2020).
2. Brasil CN de S de S. *Legislação do SUS*. (2003). Available online at: http://bvsms.saude.gov.br/bvs/publicacoes/progestores/leg_sus.pdf (accessed June 10, 2020).
3. Ministério da Saúde. *PORTARIA Nº 3.263, DE 11 DE DEZEMBRO DE 2019 - PORTARIA Nº 3.263, DE 11 DE DEZEMBRO DE 2019 - DOU - Imprensa Nacional*. (2019). Available online at: http://www.in.gov.br/en/web/dou/-/portaria-n-3.263-de-11-de-dezembrode-2019-232941846 (accessed June 19, 2020).
4. Ministério da Saúde. *Vigilância em Saúde no Brasil 2003|2019*. (2019). Available online at: http://www.saude.gov.br/boletins-epidemiologicos (accessed June 19, 2020).
5. *Instituto Brasileiro de Geografia e Estatística IBGE | Brasil em síntese | território.* (2020). Available online at: https://brasilemsintese.ibge.gov.br/territorio.html (accessed June 19, 2020).
6. Superintendência do Desenvolvimento da Amazônia. *Legislação da Amazônia*. (2020). Available online at: http://www.sudam.gov.br/index.php/institucional/58-acesso-a-informacao/86-legislacao-da-amazonia (accessed June 19, 2020).
7. De Lira SRB, da Silva MLM, Pinto RS. Desigualdade e heterogeneidade no desenvolvimento da Amazônia no século XXI. *Nov Econ.* (2009) 19:153–84. doi: 10.1590/S0103-63512009000100007
8. Castro E. Expansão da fronteira, megaprojetos de infraestrutura e integração sul-americana. *Cad CRH.* (2012) 25:45–62. doi: 10.1590/S0103-49792012000100004
9. Superintendência do Desenvolvimento da Amazônia. *Boletim Amazônia - Indicadores Socioeconômico-Ambientais e Análise Conjuntural da Amazônia Legal*. (2016). Available online at: www.sudam.gov.br (accessed June 19, 2020).
10. Leal AL, de Sá MER, Nascimento NSF, de Sousa Cardoso W. PRODUÇÃO MINERAL NO ESTADO DO PARÁ E REFLEXOS NA (RE)PRODUÇÃO DA MISÉRIA Barcarena, Marabá e Parauapebas. *Rev Polit Públicas*. (2012) 16:157–67. Available online at: http://www.periodicoseletronicos.ufma.br/index.php/rppublica/article/view/1186 (accessed June 07, 2021).
11. Lira SRB de. *Do Aviamento à Globalização, Facetas do (sub) Desenvolvimento da Economia Paraense. In XII Encontro Da Associação Nacional De Pós-Graduação E Pesquisa Em Planejamento Urbano E Regional, 23*. (2007). Available online at: http://anais.anpur.org.br/index.php/anaisenanpur/article/view/1392 (accessed June 15, 2020).
12. Uhart M, Pérez AA, Rostal M, Robles EA, Paula CD De, Miranda F. A. 'One Health" Approach to Predict Emerging Zoonoses in the Amazon," *Wildlife and Human Health: Experiences and Perspectives*. Rio de Janeiro: FIOCRUZ (2013) 1:65–73.
13. Nava A, Shimabukuro JS, Chmura AA, Luiz S, Luz B. The impact of global environmental changes on infectious disease emergence with a focus on risks for Brazil. *ILAR J.* (2017) 58:393–400. doi: 10.1093/ilar/ilx034
14. Andrade MV, Coelho AQ, Neto MX, De Carvalho LR, Atun R, Castro MC. Transition to universal primary health care coverage in Brazil: analysis of uptake and expansion patterns of Brazil's Family Health Strategy (1998-2012). *PLoS ONE.* (2018) 13:1–11. doi: 10.1371/journal.pone.0201723
15. Castro MC, Baeza A, Codec T, Cucunuba ZM, Paula A, Asta D, et al. Development, environmental degradation, and disease spread in the Brazilian Amazon. *PLoS Biol*. (2019) 17:e3000526. doi: 10.1371/journal.pbio.3000526
16. Kelly TR, Karesh WB, Johnson CK, Gilardi KVK, Anthony SJ, Goldstein T, et al. One Health proof of concept: bringing a transdisciplinary approach to surveillance for zoonotic viruses at the human-wild animal interface. *Prev Vet Med.* (2017) 137:112–8. doi: 10.1016/j.prevetmed.2016.11.023
17. Ghai S, Hemachudha T. Evaluating human rabies control in Asia: using 'One Health' principles to assess control programmes for rabies. *Rev Sci Tech.* (2018) 37:617–27. doi: 10.20506/rst.37.2.2828
18. Fooks AR, Cliquet F, Finke S, Freuling C, Hemachudha T, Mani RS, et al. Rabies. *Nat Rev Dis Prim*. (2017) 3:17091. doi: 10.1038/nrdp.2017.91
19. Walker PJ, Blasdell KR, Calisher CH, Dietzgen RG, Kondo H, Kurath G, et al. ICTV virus taxonomy profile: rhabdoviridae. *J Gen Virol.* (2018) 99:447–8. doi: 10.1099/jgv.0.001020

20. World Health Organization (WHO) and Food and Agriculture Organization of the United Nations (FAO) and World Organization for Animal Health (OIE). *First Annual Progress Report: Global Strategic Plan to End Human Deaths From Dog-Mediated Rabies by 2030*. Geneva: WHO (2019) p. 1–38.
21. Da Rosa EST, Kotait I, Barbosa TFS, Carrieri ML, Brandão PE, Pinheiro AS, et al. Bat-transmitted human rabies outbreaks, Brazilian amazon. *Emerg Infect Dis.* (2006) 12:1197–202. doi: 10.3201/eid1208.050929
22. Barbosa TFS, Medeiros DB de A, Travassos da Rosa ES, Casseb LMN, Medeiros R, Pereira A de S, et al. Molecular epidemiology of rabies virus isolated from different sources during a bat-transmitted human outbreak occurring in Augusto Correa municipality, Brazilian Amazon. *Virology.* (2008) 370:228–36. doi: 10.1016/j.virol.2007.10.005
23. Vargas A, Romano APM, Merchán-Hamann E. Raiva humana no Brasil: estudo descritivo, 2000-2017. *Epidemiol Serv Saude Rev Sist Unico Saude Bras.* (2019) 28:e2018275. doi: 10.5123/S1679-49742019000200001
24. Francelino N, Duarte H, Henrique C, Kessiene K, Cavalcante DS, Gustavo F, et al. Increased detection of rabies virus in bats in Ceará State (Northeast Brazil) after implementation of a passive surveillance programme. *Zoonoses Public Health.* (2020) 67:186–92. doi: 10.1111/zph.12670
25. *Ministério da Saúde and Secretaria de Vigilância em Saúde Esquema Para Profilaxia da Raiva Humana com Vacina de Cultivo Cellular.* (2021). Available online at: https://bvsms.saude.gov.br/bvs/folder/esquema_profilaxia_raiva_humana.pdf (accessed April 9, 2021).
26. *Brasil As Redes de Atenção à Saúde (Brasil)*. (2021). Available online at: https://www.gov.br/pt-br/servicos-estaduais/as-redes-de-atencao-a-saude (accessed April 9, 2021).
27. Ministério da Saúde. Secretaria de Vigilância em Saúde. *Esquema para profilaxia da raiva humana com vacina de cultivo celular*. Brasília, Ministério da Saúde (2020). Available online at: https://bvsms.saude.gov.br/bvs/folder/esquema_profilaxia_raiva_humana.pdf (accessed June 07, 2021).
28. Castro MC, Massuda A, Almeida G, Menezes-Filho NA, Andrade MV, de Souza Noronha KVM, et al. Brazil's unified health system: the first 30 years and prospects for the future. *Lancet.* (2019) 394:345–56. doi: 10.1016/S0140-6736(19)31243-7
29. Daumas RP, Azevedo e Silva G, Tasca R, da Costa Leite I, Brasil P, Greco DB, et al. The role of primary care in the Brazilian healthcare system: limits and possibilities for fighting COVID-19. *Cad Saude Publica.* (2020) 36:e00104120. doi: 10.1590/0102-311x00104120
30. Schneider MC, Romijn PC, Uieda W, Tamayo H, Da Silva DF, Belotto A, et al. Rabies transmitted by vampire bats to humans: an emerging zoonotic disease in Latin America? *Rev Panam Salud Publica/Pan Am J Public Heal.* (2009) 25:260–9. doi: 10.1590/S1020-49892009000300010
31. Confalonieri UEC, Margonari C, Quintão AF. Environmental change and the dynamics of parasitic diseases in the Amazon. *Acta Trop.* (2014) 129:33–41. doi: 10.1016/j.actatropica.2013.09.013
32. Ellwanger JH, Kulmann-Leal B, Kaminski VL, Valverde-Villegas JM, Da Veiga ABG, Spilki FR, et al. Beyond diversity loss and climate change: impacts of Amazon deforestation on infectious diseases and public Health. *An Acad Bras Cienc.* (2020) 92:1–33. doi: 10.1590/0001-3765202020191375
33. Maria C, Duarte R. Regionalização e desenvolvimento humano : uma proposta de tipologia de Regiões de Saúde no Brasil Regionalization and human development : a typology of health regions in Brazil Regionalización y desarrollo humano : una clasificación para las regiones de s. *Cad Saude Publica*. (2015) 31:1163–74. doi: 10.1590/0102-311X00097414
34. Dourado D de A, Elias PEM. Regionalization and political dynamics of Brazilian health federalism. *Reg Polit Dyn Brazilian Heal Fed.* (2011) 45:204–11. doi: 10.1590/S0034-89102011000100023
35. Garnelo L, Cristina R, Parente P, Laura M, Puchiarelli R, Correia PC, et al. Barriers to access and organization of primary health care services for rural riverside populations in the Amazon. *Int J Equity Health.* (2020) 19:54. doi: 10.1186/s12939-020-01171-x
36. Silveira RP, Pinheiro R. Entendendo a necessidade de médicos no interior da Amazônia - Brasil. *Rev Bras Educ Med.* (2014) 38:451–9. doi: 10.1590/S0100-55022014000400006
37. De Oliveira APC, Gabriel M, Dal Poz MR, Dussault G. Challenges for ensuring availability and accessibility toin health care services under Brazil's unified health system (SUS). *Cienc Saude Coletiva.* (2017) 22:1165–80. doi: 10.1590/1413-81232017224.31382016
38. Albuquerque MV de, Viana AL d'Ávila, Lima LD de, Ferreira MP, Fusaro ER, Iozzi FL. Desigualdades regionais na saúde: mudanças observadas no Brasil de 2000 a 2016. *Cien Saude Colet.* (2017) 22:1055–64. doi: 10.1590/1413-81232017224.26862016
39. Evangelina XG de Oliveira, Marília Sá Carvalho, Cláudia Travassos. Territórios do Sistema Único de Saúde-mapeamento das redes de atenção hospitalar. *Cad Saúde Pública.* (2004) 20:386–402. doi: 10.1590/S0102-311X2004000200006
40. Viacava F, Ricardo D, Jaime X, Bellido G. *Projeto Brasil Saúde Amanhã: Relatório de Pesquisa Sobre Internações na Esfera Municipal*. Rio de Janeiro: FIOCRUZ (2014) 2:1–168.
41. Ministério da Saúde. *PORTARIA Nº 2.436* (2017). Available online at: https://bvsms.saude.gov.br/bvs/saudelegis/gm/2017/prt2436_22_09_2017.html (accessed April 17, 2021a).
42. Rupprecht CE, Fooks AR, Abela-Ridder B. *Laboratory Techniques in Rabies*. 5 ed. Geneva: WHO (2018), 1:1–304.
43. Velasco-Villa A, Escobar LE, Sanchez A, Shi M, Streicker DG, Gallardo-Romero NF, et al. Successful strategies implemented towards the elimination of canine rabies in the Western Hemisphere. *Antiviral Res.* (2017) 143:1–12. doi: 10.1016/j.antiviral.2017.03.023
44. Schneider MC, Belotto A, Adé MP, Hendrickx S, Leanes LF, Rodrigues MJDF, et al. Current status of human rabies transmitted by dogs in Latin America. *Cad Saude Publica.* (2007) 23:2049–63. doi: 10.1590/S0102-311X2007000900013
45. Ministério da Saúde. *Secretaria de Vigilância em Saúde*. *Protocolo de Tratamento da Raiva Humana no Brasil*. Brasília: Ministério da Saúde. (2011), 1: 12–9.
46. Banyard AC, Horton DL, Freuling C, Müller T, Fooks AR. Control and prevention of canine rabies: the need for building laboratory-based surveillance capacity. *Antiviral Res.* (2013) 98:357–64. doi: 10.1016/j.antiviral.2013.04.004
47. Aylan O, El-Sayed AFM, Farahtaj F, Janani AR, Lugach O, Tarkhan-Mouravi O, et al. Report of the first meeting of the middle East and Eastern Europe rabies expert Bureau, Istanbul, Turkey (June 8-9, 2010). *Adv Prev Med.* (2011) 2011:1–4. doi: 10.4061/2011/812515
48. Slate D, Algeo TP, Nelson KM, Chipman RB, Donovan D, Blanton JD, et al. Oral rabies vaccination in North America: opportunities, complexities, and challenges. *PLoS Negl Trop Dis.* (2009) 3:e549. doi: 10.1371/journal.pntd.0000549
49. Fehlner-Gardiner C. Rabies control in North America-past, present and future. *Revue scientifique et technique (International Office of Epizootics)*. (2018) 37:421–37.
50. Fernandes MEB, Da Costa LJC, De Andrade FAG, Silva LP. Rabies in humans and non-human in the state of Pará, Brazilian Amazon. *Brazilian J Infect Dis.* (2013) 17:251–3. doi: 10.1016/j.bjid.2012.10.015
51. De Andrade FAG, Gomes MN, Uieda W, Begot AL, Ramos ODS, Fernandes MEB. Geographical analysis for detecting high-risk areas for bovine/human rabies transmitted by the common hematophagous bat in the Amazon region, Brazil. *PLoS ONE.* (2016) 11:1–15. doi: 10.1371/journal.pone.0157332
52. Benavides JA, Megid J, Campos A, Rocha S, Vigilato MAN, Hampson K. An evaluation of Brazil's surveillance and prophylaxis of canine rabies between 2008 and 2017. *PLoS Negl Trop Dis.* (2019) 13:1–16. doi: 10.1371/journal.pntd.0007564
53. World Health Organization (WHO). *Rabies Vaccines and Immunoglobulins: WHO position*. Geneva: WHO (2018) 33:442–3.
54. Jamile L, Emanuel M, Fernandes B. Rabies : knowledge and practices regarding rabies in rural communities of the Brazilian Amazon basin. *PLoS Negl Trop Dis*. (2016) 10:e0004474. doi: 10.1371/journal.pntd.0004474
55. Guo C, Li Y, Huai Y, Rao CY, Lai S, Mu D, et al. Exposure history, post-exposure prophylaxis use, and clinical characteristics of human rabies cases in China, 2006–2012. *Sci Rep.* (2018) 8:1–10. doi: 10.1038/s41598-018-35158-0
56. Sudarshan MK, Haradanhalli RS. Facilities and services of postexposure prophylaxis in anti-rabies clinics: a national assessment in India. *Indian J Public Health.* (2019) 63:S26–30. doi: 10.4103/ijph.IJPH_367_19
57. Sreenivasan N, Li A, Shiferaw M, Tran CH, Wallace R, Blanton J, et al. Overview of rabies post-exposure prophylaxis access, procurement and distribution in selected countries in Asia and Africa, 2017–2018. *Vaccine.* (2019) 37:A6–13. doi: 10.1016/j.vaccine.2019.04.024

58. Kessels JA, Recuenco S, Navarro-Vela AM, Deray R, Vigilato M, Ertl H, et al. Pre-exposure rabies prophylaxis: a systematic review. *Bull World Health Organ.* (2017) 95:210–9C. doi: 10.2471/BLT.16.173039
59. Bhan N, Rao KD, Kachwaha S. Health inequalities research in India: a review of trends and themes in the literature since the 1990s. *Int J Equity Health.* (2016) 15:1–8. doi: 10.1186/s12939-016-0457-y
60. Viana RL, de Freitas CM, Giatti LL. Saúde ambiental e desenvolvimento na amazônia legal: Indicadores socioeconômicos, ambientais e sanitários, desafios e perspectivas. *Saude e Soc.* (2016) 25:233–46. doi: 10.1590/S0104-12902016140843
61. Santana RS. *SUS Para Todos? Avanços e Desafios nas Políticas Farmacêuticas Para Doenças da Pobreza.* (2017). Available online at: http//repositorio.unb.br/bitstream/10482/23594/1/2017_RafaelSantosSantana.pdf, 217 (accessed June 19, 2020).
62. Garnelo L. Especificidades e desafios das políticas públicas de saúde na Amazônia. *Cad Saude Publica.* (2019) 35:e00220519. doi: 10.1590/0102-311x00220519
63. Vercauteren K, Ellis C, Chipman R, Deliberto T, Shwiff S, Slate D. *Rabies in North America: A Model of the One Health Approach.* USDA Natl. Wildl. Res. Cent. - Staff Publ. (2012). Available online at: http://digitalcommons.unl.edu/icwdm_usdanwrc/1202 (accessed June 07, 2021).

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Public Health

HYPOTHESIS AND THEORY
published: 30 June 2021
doi: 10.3389/fpubh.2021.617003

One Health of Peripheries: Biopolitics, Social *Determination*, and Field of Praxis

Oswaldo Santos Baquero [1,2*]

[1] *Department of Preventive Veterinary Medicine and Animal Health, School of Veterinary Medicine and Animal Science, University of São Paulo, São Paulo, Brazil,* [2] *Research Group on Peripheries, Institute of Advanced Studies, University of São Paulo, São Paulo, Brazil*

Amid the urgency to solve countless and severe health problems, asking what is health or who can and must have it may seem like a waste of time. However, some responses can reveal prevailing practices that divert attention from fundamental problems, thus maintaining privileges and deepening health inequities. One Health of Peripheries arises from these questions and takes three interdependent senses. The first refers to attributes determining the well-being and suffering of peripheral multispecies collectives: a state, a process, the realization of capacities. The second problematizes marginalizing apparatuses that define health and who can and should have it. The third encompasses practices in more-than-human social spaces in which, and through which, One Health is experienced, understood, and transformed. The qualification of health as "one" does not refer to the lack of plurality, nor to the simple aggregation of health fragments (human + animal + environmental), but to the complexity of health in a field with peripheral places, ensuing from margins to privilege those who are inside and legitimize the exploitation of those who are outside. The interaction among margins creates degrees and kinds of privilege and vulnerability that materialize epidemiologic profiles while articulating different peripheral strengths and needs supports a collective resistance to break margins. Social *determination,* a key concept in the (Latin American) collective health movement, underlies such profiles. However, this movement overlooks the more-than-human dimension of social determination; that is to say, One Health of Peripheries is a blind spot of collective health. The cartography of One Health of Peripheries has unique needs regarding participation, research, and inclusive policies for the decolonial promotion of healthy lifestyles.

Keywords: one health of peripheries, one health, collective health, critical epidemiology, social determinants of health, health inequities, more-than-human biopolitics, critical animal studies

OPEN ACCESS

Edited by:
Laura H. Kahn,
Princeton University, United States

Reviewed by:
Maya K. Gislason,
Simon Fraser University, Canada
Susan Leigh Craddock,
University of Minnesota Twin Cities, United States

****Correspondence:***
Oswaldo Santos Baquero
baquero@usp.br

Specialty section:
This article was submitted to Planetary Health, a section of the journal Frontiers in Public Health

Received: *13 October 2020*
Accepted: *28 May 2021*
Published: *30 June 2021*

Citation:
Baquero OS (2021) One Health of Peripheries: Biopolitics, Social Determination, and Field of Praxis. Front. Public Health 9:617003. doi: 10.3389/fpubh.2021.617003

INTRODUCTION

What is health, who can be healthy, and what are the most pressing health issues? I will argue that prevailing answers so far have been biased by struggle, cooperation, and imposition to shape and legitimize hierarchies according to the interest of the most privileged hierarchical positions.

Conceptual frameworks about the social *determination* of health (1, 2) and the social determinants of health (3) consider social hierarchies, giving us insights and tools to oppose specific health inequities. However, one of my claims in this paper is that at the same time, these frameworks ignore and reproduce some marginalizing apparatuses that materialize more-than-human health inequities.

Drawing from Foucault (4) and Agamben (5), I take as apparatus the system of relations between discursive practices, institutions, and more generally, anything with the capacity to determine, control, model, or administer living beings. By marginalizing apparatuses, I mean those that establish margins and legitimize the exploitation and violence against living beings at the other side of the margins, attributing to them and their interests less value while silencing their resistance and agency.

Peripheries are beyond the margins. Patriarchy margins create gender peripheries, just as species margins produce species peripheries. The same happens with racial, ethnic, and geographic margins, among others.

The (Latin American) collective health field (6, 7) has been concerned with some peripheries but systematically produces and reproduces apparatuses that marginalize non-human animals (hereafter animals). In collective health, animals have instrumental value to prevent and control specific human health problems. However, they do not figure as health bearers or in any other explicit form in its conceptual frameworks about the social determination of health. Although such marginalization is common to different health perspectives, I will focus my critic on the collective health field because it is one of the main influences on One Health of Peripheries.

Is the marginalization of animals from the field of collective health justified? I will conclude that it is not. The bourdieusian's approach that supports this field (6) and critical analysis of social hierarchies (8) also shows, together with other perspectives, the more-than-human dimension of social entanglements (9–12). Moreover, concerns with health inequities can be better addressed considering theories of multispecies justice (13), while labor perspectives of health [see Almeida-Filho's discussion about Laurell's works (14)] could be updated by more-than-human labor theories (15).

Health is not exclusively human, as demonstrated by the overwhelming One Health scientific evidence about the human-animal-environment interface (16). One Health is supported by intersectoral and international initiatives due to its pertinence to address pandemics, bioterrorism, food-borne diseases, and significant health problems expected to worsen, such as antimicrobial resistance (16, 17). However, One Health approaches often omit social processes from empirical analysis and theoretical explanations. They encourage intersectoral collaboration as if it were a matter of symmetrical negotiation between institutions, or even more problematic, a matter of global North assistance for the global South (18).

The biologism in One Health has remarkable exceptions (19–25). Here I propose another one: One Health of Peripheries. I rethink One Health from the perspective of Latin American collective health, more-than-human biopolitics, and other critical approaches. Inevitably, this brings together contradictions and some incommensurable aspects. However, we must embrace these challenges instead of assuming that we can translate convenient solutions for ideal settings to a real-world full of contradictions and power relationships, far from being a coordinated network of rational actors.

The epistemologies of the South offer us alternatives such as the ecology of knowledge (26) and hybrid cultures (27), among others, to think complexity, contradiction, plural knowledge, and intercultural translation. That said, my objective here is not to make remarkable advancements in epistemic translation. Instead, in this paper, I point to some conceptual tools that help to identify peripheries and break margins. It is a starting point to introduce One Health of Peripheries, its social determination, and an explicit commitment to advance structural alternatives for multispecies justice. In a separate paper, we elaborate more on the ecology of knowledge, the decolonial stance of One Health of Peripheries, and seven actions to promote the health of marginalized multispecies collectives (18).

The following sections of the paper sketch the emerging field of One Health of Peripheries. A field requiring new practices and policies as well as including other actions already existing but applied elsewhere. Notwithstanding the relevance, my objective here is not to address specific procedures to conduct health practices or concrete recommendations to guide health policies. The *more-than-human biopolitics* section locates marginalizing apparatuses in a broader biopolitical field. It then outlines the role of domestication and animalization in the establishment and operation of hierarchies that determine epidemiologic profiles; it also elaborates on the intersection of margins as well as on possibilities of resistance. The One *Health* section rethinks One Health and draws initial cartography of its peripheral regions. The *social determination of health* section briefly compares the concepts of social determination of health and social determinants of health. From this comparison and the previous sections, I extend the idea of triple inequity of health to include other forms of inequities and their interactions, with particular attention to species-based inequities. The *field of praxis* section is based on Bourdieu's concepts of *habitus* and *field* and Freire's understanding of praxis. In that section, I frame One Health of Peripheries as a blind spot of collective health. Finally, I present some concluding remarks.

MORE-THAN-HUMAN BIOPOLITICS

Biopolitics addresses new forms of power or aspects of power previously unknown, in the context of phenomena as diverse as concentration camps, migratory processes, cognitive capitalism, domestication, sovereignty, the immunitary paradigm of modern politics, the relationship of humans with others animals and with technology, the state of exception, and power/knowledge relationships (4, 28–37). Such diversity brings ambivalence and contradiction as well as negative (marginalizing, excluding, repressing) and positive (affirmative, productive, empowering) perspectives. Biopolitics shows the blurring of the public/private boundary, the politics on life and of life, the administration of populations, the production of profitable and docile bodies, and marginalizing apparatuses underlying hierarchies (31, 36, 38).

Here it is convenient to come back to the notion of apparatus as the system of relations between discursive practices, institutions, and more generally, anything with the capacity to determine, control, model, or administer living beings. This notion is related to the authorities of delimitation (39)—"including philosophical, religious, scientific and legal"—that delimit and authorize margins and legitimize their practices (40). As one can read in Derrida (41), the original marginalization is constitutive of the socialization of "human culture and of politics itself"; it is a marginalization that leaves animals on the periphery and allows their domestication. Such domestication gives rise to disciplinary and violent regimes (40) and to population technologies for the administration of life. It becomes a model of exploitation and establishes the basis of hierarchical orderings.

Animal domestication required demographic technologies to control population densities, a complex mixture of enforcement and behavioral tactics to administer animal resistance, and care procedures to sustain life. The ensuing more-than-human social relationships established a complex network of codetermination. Demographic technologies for animals allowed human demographic processes of growth and specialization. Food surplus stimulated the formation of storage specialists, leading to positive feedback on food surplus and available time for the emergence of population administrators, accumulation experts, and bureaucrats (42). Animals were not the unique target of the mentioned mixture.

The increasing size and complexity of multispecies settlements was the basis for further social differentiation, unequal distribution of resources, and colonization (42, 43); a process resting on the war against animals (44), the domestication of human collectives, and technologies of accumulation.

Domestication also determined another phenomenon of relevance for more-than-human health. Higher multispecies densities set an appropriate scene for emerging zoonoses and epidemics. So domestication is also a history of epidemics, turned into pandemics by colonization.

The biopolitics of domestication is not a finished remote history. Medical textbooks for 19th-century landowners described procedures to reproduce slaves and increase their productive efficiency, in many respects indistinguishable of current livestock production procedures: compartmentalization of facilities; populations divided according to demographic criteria of productive and reproductive interest; classification and monitoring of morbidity and mortality; prevention of communicable diseases; reproductive selection (genetic improvement); hygiene, nutrition, socialization, and other generic practices to reduce losses of biological capital [see the documented analyses of such practices by Smithers and Camacho (45, 46)]. In the 20th century, the anti-Semite Henry Ford talked in his autobiography about the disassembly line of a Chicago slaughterhouse that inspired his assembly-line method (47, 48), which in turn informed assembly lines to kill Jews in Nazi Germany (30, 48). In the current century, big data and artificial intelligence fuel genetic and molecular interventions and disease surveillance across species, sophisticating biopolitics and further blurring binary distinctions: natural/artificial, human/non-human, public/private.

Marginalizing apparatuses come into play when biopolitics inflict suffering and produce privileges. They are constituents of speciesist, racist, ethnic, class, gender, capacity, and geographic marginalization. Furthermore, the interaction among marginalizing apparatuses creates more peripheries.

Animalization is a marginalizing apparatus applied to some human groups. As recently as 1920, the Wildlife Conservation Society (the same institution that decades later proposed the One Health concept) was responsible for exhibiting Ota Benga, a young black man, at the Bronx Zoo (49). Pugliese makes a "deanthropocentric" reading of Foucault's Madness and Civilization to argue that the lack of rationality operated the animalization of the so-called mad people, justifying their confinement and physical restriction (40). Besides these and other conspicuous examples of animalization, more nuanced practices reinforce human marginalization (think in everyday language). Moreover, animalization also operates in animals, establishing a category of exploitable beings for human benefit.

It is worth noting that animalization does not consistently downplay animals. Sometimes "animal" features are exalted and attributed to humans (fondness, strength, agility) while "human" characteristics (criminal, terrorist, beggar) justify violence against certain human groups. Animalization is inherently aporetic as it operates on who is already an animal, whether human or not. Furthermore, animalization is not involved in all cases of human marginalization.

The interaction between marginalizing apparatuses encompasses more than animalization. Social class determines the material resources of multispecies households. The opportunities for humans and animals (especially the fate of farm animals) are conditioned by disability and sex. Gender is strongly associated with animal protection advocacy. Concentrated Animal Feeding Operations exploit animals and hire marginalized ethnic groups to do unhealthy jobs (50). The racial marginalization of human communities affects the multispecies collectives with which those humans entangle.

The above examples show that some margins directly intersect each other only in humans, others intersect in humans and animals, while others simultaneously segregate multispecies collectives. Race, gender, class, and ethnic margins rest on human attributes, and through them, they affect multispecies collectives. Species, sex, and disability margins target human and animal subjects. Geographic margins segregate multispecies collectives.

The examples are gross simplifications of more complex intersections. A Black non-heteronormative woman living in a favela and protecting animals faces the burden of multiple margins that compromise the capacity to care for her animals. Worsened animal health and insufficient reproductive control increase the psychological and economic demands, while zoonotic spread and animal overpopulation exacerbate the community burden. Moreover, many humans residing in favelas were small farmers displaced by agribusiness apparatuses that at the same time have devastating consequences for traditional communities, wildlife, and exploited farm animals and workers.

The idea of intersecting margins is not new. It is at the core of intersectionality, which emerged to address the legal limitations to repair injustices suffered by Black women (51). One of the claims of intersectionality is that the marginalization of black women is not the sum of sexist and racist burdens; sex discrimination is not equally experienced by Black and White women, just as racial discrimination differs between Black men and women (51). Intersectionality has evolved among scholars and activists, bringing together awareness, confusion, overuse, and deeper explanations. The multiplicity of intersectional concerns has grown because there are many heterogeneous marginal experiences.

The overlay of peripheries produces particular experiences of marginalization and resistance without requiring that attributes of direct marginalization are present in the same individual (as some examples above showed). Furthermore, different peripheries share borders, giving rise to a remarkable possibility: articulating each periphery's strengths and needs supports a collective resistance not to turn hierarchies upside-down but to break margins. Thus, marginalized multispecies collectives can strengthen intersectionality and benefit from it, but that requires effective articulation, a non-trivial task.

Earlier, I mentioned accumulation experts and accumulation technologies. Later, the examples of multispecies intersectionality implicitly showed that capitalism is a shared marginalizing apparatus, that is to say, a common target of intersectional resistance. The biopolitics of animal populations was a condition of possibility for human biopolitics, colonization, and capitalism. These, in turn, reinforced and sophisticated animal biopolitics and produced other marginalizing apparatuses. Therefore, what is at stake is far from being a unidirectional process. A complex network of power relationships constantly moves margins in multiple directions, so individual and collective experiences of marginalization are also dynamic.

Marginalizing apparatuses mobilize exploitation, care, administration, discipline, subjectification, resistance, affects, and legitimization. They produce and reproduce peripheries that partially determine the health experience of multispecies collectives.

ONE HEALTH

One health traditionally refers to the inextricable relationship between human, animal, and environmental health. It is a concept growing in popularity and application due to the increasing awareness regarding many human diseases with an animal origin and the multiple diseases that remain zoonotic; from AIDS to dengue and COVID-19, from visceral leishmaniasis to tuberculosis and influenza A (52–54). According to the World Organization for Animal Health (OIE), 60% of human infectious diseases are zoonotic, 75% of emerging human infectious diseases originate from other animal species, and 80% of agents with bioterrorist potential are zoonotic (17). Neglected tropical diseases are mostly zoonotic or vector-borne (55) and affect more than a billion people (56) as well as a high number of animals. Neglected tropical diseases are a priority recognized by the World Health Organization (WHO), particularly in its road map for 2021–2030, which recommends One Health approaches, to attain the Sustainable Development Goals (57). In the face of growing global concern about emerging and re-emerging zoonoses and antimicrobial resistance due to indiscriminate overuse of antibiotics in human populations and other species, One Health catalyzed the tripartite union between the WHO, the OIE, and FAO (16). More recently, One Health approaches entered in the general and specific objectives of the European Union *Programme for the Union's action in the field of health ("EU4Health Programme") for the period 2021–2027* (58).

One Health is often represented as three partially intersected sets (human, animal, environment). Thus, although humans and animals are *within* the environment, part of the human and animal sets is outside it. Furthermore, the partial intersection between the human and animal domains is incongruent with evolutionary theory since humans are animals. Of course, representations can emphasize different issues; however, there is no need to leave part of the sets out of the intersection. Subsumption serves to represent the relationships, and it is in line with the inclusiveness required to promote One Health of Peripheries.

One Health of Peripheries, does not dogmatically cut animal taxonomy to leave the human species on one side, and a wide variety of species on the other side (**Figure 1**). Instead, there are multispecies collectives whose species-specific constitution depends on the health phenomenon in question; the division of animal taxonomy into "human" and "animal" is understood as a tool that may have didactic and strategic values and serve as semantic abbreviation; however, the uncritical use of this tool conflates the division with a constant of "nature" and hides its biopolitical consequences.

In One Health of Peripheries, the environment is not understood as an external domain related or partially intersected by the human and animal domains. It is composed of multispecies collectives, so multispecies studies can help to think about it (10–12, 59); the environment is a set of relations and agents located by them; entanglements; agents that even as "individuals" reveal internal environments of microbiota; complex assemblages of holobionts (60). It is an environment without the dual ontology separating "human society" and "nature" (10, 12, 61, 62).

There are many holistic approaches to promote the health of such an environment. Many indigenous peoples have lived over centuries with a sense of integration reflected in sustainable and respectful environmental practices. Agroecology has learned from them, incorporates contemporary technologies, and brings equity to the center (63, 64). Living cities, recombinant ecosystems, and other movements of sustainable urban systems offer alternatives for cities (65–67). However, the colonial mentality and capitalist order deplete resources and marginalize collective endeavors driven by well-being instead of profit. Thus, breaking marginalizing apparatuses is as crucial here as elsewhere.

Besides the substantial difference between conventional One Health and One Health of Peripheries as conceptual frameworks, the last departs from the first in other directions. One Health of Peripheries is a polysemic expression with an ontological, an epistemological, and a practical sense. The first sense refers to attributes determining the well-being and suffering of peripheral multispecies collectives: a state, a process, the realization of capacities (note that capacity is a key notion in

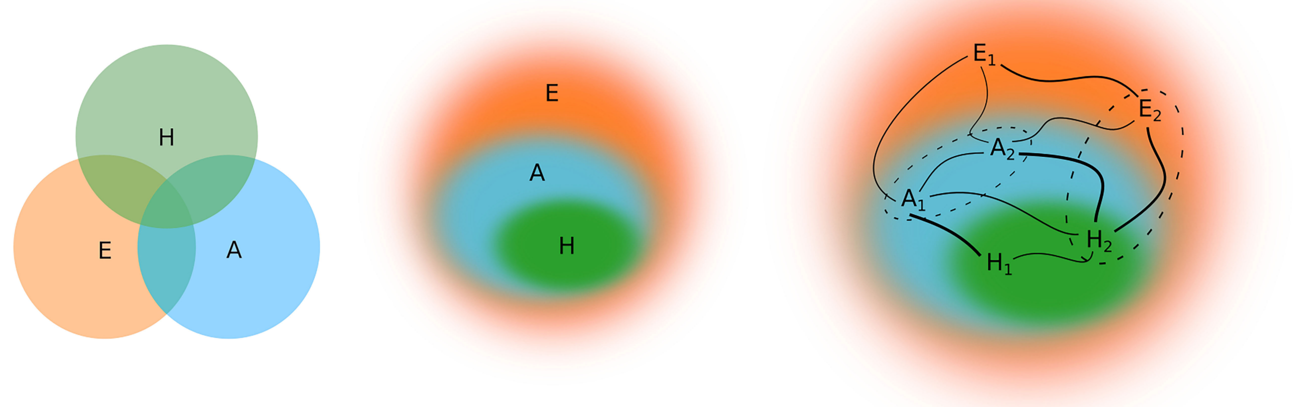

FIGURE 1 | The conventional scheme partially intersect human, animal, and environmental health. In the proposed scheme of One Health, there is subsumption (*One* Health, inclusiveness, internal environments with blurred boundaries), differentiated relations (edges of different thickness), and plurality (indexed elements). a: non-human animal (species/collective/individual/intraindividual); h: human-animal (collective/individual/intraindividual); and e: vegetables, other living beings, inanimate agents (species/collective/individual/intraindividual). Dashed boundaries show that there are many configurations for multispecies collection.

health promotion). The second problematizes the marginalizing apparatuses that determine health. The third encompasses practices against marginalization that informs and reinforces peripheral resistance and learns from it.

These three senses are not independent; each one is inherent to the others. While understanding and practice are attributes of multispecies collectives, attributes and understandings are practices and transformed by practice. Simultaneously, understanding gives sense to attributes and practices. This polysemy has material consequences, as theorizing new attributes lead to other practices to pursue the wellness of marginalized multispecies collectives.

The emphasis on marginalizing apparatuses has as a corollary the existence of an heterogeneous peripheral cartography. Thus, what follows in this section is an outline of peripheral regions that are anything but the whole cartography. Choosing some peripheries and not others is not an unproblematic decision; it can reinforce marginalization. Indeed, we cannot do everything simultaneously, but for that very reason, we must problematize what is at stake in prioritization. My decision is somehow arbitrary and shaped by my background. Nevertheless, I hope it sheds some light on pathways to identify and fracture even the margins I omit.

Neglected Diseases

With renowned institutions listing neglected diseases, it is easier to see how the pharmaceutical industry disregards the needs of unprofitable populations. However, stressing diseases might divert attention from a fundamental point of neglect. Many tourists have information about the safer travel periods to avoid malaria, access to preventive medication, and health insurance to receive the best available treatment regime if they got infected. Rabies vaccine has been around for decades, but approximately 60 thousand humans die of rabies each year, mainly in the global South. Thus, not anybody with a neglected disease is neglected and what is at stake is not only the existence of pharmaceutical treatments.

The fundamental neglect resides on multispecies collectives and demands more than outreach policies. People representing those collectives need effective political inclusion; plural education to solve their problems and sustainably build their communities; food security and sovereignty; the multispecies collectives need more-than-human health systems and decolonial programs for caring ecosystems.

Domestic Violence

Violence is a cause of morbidity and mortality, and among the approaches to address its complexity, it is the prevention of violence against animals. Conviviality with companion animals is growing, and in some countries, there are more dogs and cats than children in households (68, 69). In multispecies homes, animals enter into family dynamics and can be victims of domestic violence. The violence against them is related to the violence against children and women (70–74). In addition to victims, animals are instruments of coercion used by perpetrators to cause more suffering and control their human victims (75–79).

Domestic violence does not stem exclusively from individual psychological factors. Lifestyles, conditioned by processes of social reproduction, favor or protect against domestic violence, depending on their configuration. Therefore, it is important to consider the relationship between social vulnerability, interpersonal violence, and violence against companion animals (80–84).

The investigation of violence against animals helps to detect domestic violence cases involving several victims and broadens the understanding of the perpetrators' psychological profile (73). Furthermore, animals can promote collective care and self-care to counter violence (85, 86). However, the effective prevention of domestic violence must address social vulnerability and its social determination, in the broad sense, without being restricted to economic poverty and exploring underlying marginalizing apparatuses. It must dismantle the patriarchal apparatus underlying domestic violence. Domestic violence in One Health of Peripheries is socially determined, affects humans and animals, and has institutionalized dimensions.

Geographic Peripheries

Geographic peripheries are heterogeneous, encompassing countries, areas circumscribed within countries, and cross-border regions such as rural areas, indigenous territories, and favelas. Taking the last as an example, we can see how geographic marginalization also circumscribes epidemiologic profiles. *Favela* is a term with pejorative connotations, unsolved by euphemisms. It refers more directly to the geographically delimited precariousness ensuing from the historical exploitation and concentration of wealth. Simultaneously, its polysemy point to the constant meaning-making and remaking from within; to the place from which resistance, creativity, and sensitivity produce other epistemologies and lifestyles.

The favelas challenge conventional census methods and thus receive differentiated treatment, starting from their identification. For instance, the Brazilian Institute of Geography and Statistics (IBGE) defines favelas as places with at least 51 housing units irregularly occupied, under urban irregularities, or lacking essential public services (87). It calls them subnormal agglomerates. Census definitions, although limited, give an idea of quantity. There were 6,329 favelas in which 6% of the Brazilian population lived in 2010. The State of São Paulo had the highest concentration of households in favelas (23.2%), including ∼11% of its metropolitan population (87). Thus, health problems affecting favelas compromise millions of individuals in the country. Globally, projections suggest that in 2030 the human population will be 8.1 billion, 5 billion (61.7%) will live in urban areas, and 2 billion (24.7%) will live in favelas (88).

The neglect of favelas continues worldwide. The health in favelas is different from the urban health and health in poverty because not all people living in favelas are poor, and not all poor people in cities live in them (89). The favelas' contextual effects on health are mediated by imposed risks and the lack of resources (money, time, infrastructure, knowledge), establishing a vicious circle of vulnerability due to the increased burden of diseases that compromises the individuals' opportunities for economic and social inclusion.

The favelas' contextual effects impinge on multispecies collectives, and this is even more neglected. Animals are exposed and vulnerable to pollution, humidity, darkness, insufficient ventilation, malnutrition, and high population densities. There is a need to promote animal health for the sake of the animals but also for the sake of humans living with them. The life cycle of animals is shorter than in humans. Its monitoring contributes to the early detection of chronic diseases and other health problems resulting from exposure to unhealthy environments (90, 91). As favelas' boundaries are not hermetic and do not entirely restrict their contextual effects, improving their health reflects outside them. Favelas are peripheral but not isolated. Turning favelas into healthy places reduce infectious diseases, the need to use antibiotics, and thus antimicrobial resistance, one of the top ten global health problems according to the WHO. But as with any periphery, that turn requires structural changes, the dismantling of the underlying marginalizing apparatuses.

Homelessness

"Homelessness" usually refers to the condition of humans without a permanent residence, a dynamic situation that can vary from 1 day to a lifetime, depending on the availability of social and economic resources to have access to such permanent residence.

Homelessness is a structural problem of social organization around private property, worsened by the precariousness of working conditions and welfare policies. However, it also results from other processes, such as the abandonment of homes to escape domestic violence or home dynamics incompatible with drug abuse, psychiatric illnesses, and other conditions.

In addition to humans, companion animals can turn homeless due to abandonment or because they got lost. They may be born homeless, remaining as such for the rest of their lives or until rescue.

Dogs and cats are still properties, and therefore their homelessness also represents a private property problem. On the one hand, the legal consequences of abandoning an animal property might not be sufficiently persuasive to avoid animal abandonment. On the other hand, the property status might reduce and even eliminate the moral responsibility regarding animal abandonment.

Although the processes that lead humans and companion animals to homelessness are different, some effects are similar regardless of the species. Homeless individuals suffer abuse. Adversities (climatic, nutritional, emotional) cause suffering and compromise the immune system, thus adding to the lack of hygiene that predisposes to infectious diseases, worsened by the lack of access to health services.

In their marginalized condition, homeless humans and dogs find each other and create emotional bonds (92, 93). Humans even prioritize dogs when sharing available food (94), and may prefer to remain on the streets than stay overnight in places that do not accept their canine companions (95). Citing Sakelaropoulos et al. (96), Taylor describes the humans' emotional bonds with cats and even rats (93). The latter and other synanthropic species live on public spaces and pose specific challenges that increase the health complexity of multispecies collectives living on the streets.

Direct actions on homeless multispecies collectives could involve networks of shelters and adoption programs for humans (mainly children in the case of adoption) and companion animals, as well as contraceptive and "humanitarian" elimination programs for synanthropic populations. These actions complement but do not replace structural approaches of health promotion and disease risk prevention.

Regardless of their species, the homeless are members of the living cities conceptualized in critical geography (65). One Health in the urban context turns out to be the health of these living cities, and their improvement demands special considerations about homelessness. First, promoting lifestyles as opposed to the conditions that lead humans and companion animals to homelessness. Second, urban planning to promote biodiversity; planning for the so-called recombinant ecosystems and green cities (65, 67).

Agribusiness Externalities

Ending hunger is one of the United Nations' Sustainable Development Goals (97). Agribusiness has responded to such a goal by intensifying production, reducing food prices, generating jobs, and contributing to Gross Domestic Product (GDP). However, qualifying that response requires taking externalities into account. Although some externalities are gaining visibility, others remain peripheral.

The Intergovernmental Panel on Climate Change (IPCC) concluded, with a high level of confidence, that "climate change is expected to lead to increases in ill-health in many regions and especially in developing countries with low income, as compared to a baseline without climate change" (98). Greenhouse gases (GHG) are the leading cause of climate change (99), and farm animals are the largest source in agriculture (100). Furthermore, single-crop farming is another source of GHG itself. Its expansion often leads to more emissions due to the intensification of farm animal production to compensate for the loss of pastures (101).

The expansion of agricultural frontiers reduces biodiversity and increases the risk of many zoonoses occurrence (102). However, zoonoses control proposals are typically biomedical or focused on proximate risk factors. They hardly question the food production systems' *status quo*, thus losing the opportunity to find more favorable scenarios in terms of zoonoses, protection of biodiversity, and other externalities. Moreover, the loss of biodiversity is rarely understood as a direct One Health problem, characterized by increases in mortality rates of multiple animal and plant species (103), *and* losses of multiple ethnic collectives.

Water consumption and pollution are other externalities of agribusiness. In Brazil, for example, it is estimated that land irrigation consumes 72% of the country's water supply (104), and feeding farm animals consume 79% of the cultivated protein (105). Simultaneously, the water network did not serve 33.2 million people in 2018 (106). In animal production systems, sources of water pollution include pharmaceutical residues (including antibiotics), heavy metals, chemicals, excrement, and pathogens; as for crops, in addition to heavy metals and chemicals, pesticides with carcinogenic potential are of particular concern (107).

Agribusiness creates jobs and contributes to GDP. However, it matters what kind of jobs, in a context of employees with little bargaining power against growing oligopolies (108, 109). For instance, in subaltern countries, subsidies persuade smallholders to submit themselves to exploitation by transnational corporations at the expense of agrarian reforms to promote diversified agriculture equitably (108, 109). Meanwhile, in rich countries, unhealthy conditions in intensive production systems difficult the recruit domestic workers, which has been circumvented by hiring immigrants, including those who are not authorized to work. (110, 111).

Unhealthy work can occur for several reasons. In the production of fruits and vegetables, pesticides are potential carcinogens (107, 112, 113). In intensive animal production systems, toxic gases, vapors, and particles pollute the air and cause respiratory diseases (114–116). Farm environments and slaughterhouses can predispose to physical trauma, depression, and drug use (50, 111). Stressful and overpopulated environments also predispose to animal diseases, and their treatment with antibiotics results in antimicrobial resistance affecting human workers and their families (117–120). In slaughterhouses, the mass killing of animals is a violent job that can affect the employees' mental health, and slaughterhouse employment has been causally linked to increased crime rates in communities neighboring such slaughterhouses (121).

The externalities on farm animal wellness have been explored elsewhere (109, 122). Here I want to emphasize that despite recent theoretical advances on multispecies justice and labor issues involving animals (13, 15), forcing animals to produce continues without considering labor rights for them. Farm animals are subjected to a commodification strategy that transforms the violence perpetrated on sentient beings into procedures to increase production efficiency.

While happy farm animals appear in bucolic images (in children's books and milk packages) and Ag-gag laws prevent the investigation and disclosure of animal abuse (123, 124), the real farm animals are pushed to their physiological limit, constantly expanded by genetic, medical, and pharmacological technologies. Billions of these animals are slaughtered, requiring hasty procedures that challenge labor safety and animal suffering mitigation. Moreover, cruelty procedures continue in use: male chicks shredded alive when the objective is egg production; sows housed in cells that prevent them from turning their bodies; small cages that do not allow birds to extend their wings; prematurely broken mother-offspring bonds; routine amputation and without anesthesia of beaks, teeth, horns, and tails to increase confinement density and avoid cannibalism ensuing from the stressing environment.

Agribusiness produces externalities protected by strategies of governmentality (109). It destroys the environment and uses cruel methods against animals. Simply talking about job creation and GDP contribution does not say anything about the working conditions or the profit distribution. Externalities, including subsidies, outweigh the final prices paid by consumers of agribusiness' commodities and threaten global sustainability. Agribusiness marginalize multispecies collectives inside and outside farms.

SOCIAL DETERMINATION OF HEALTH

There are discussions about health complexity beyond biomedical issues. In Latin America, social medicine (nowadays collective health and critical epidemiology) has developed conceptual frameworks for the social determination of health since the 1970s. After the turn of the century, the WHO has popularized a conceptual framework of the social determinants of health. Despite criticisms from critical epidemiology to the WHO proposal for being in practice more complicit with the *status quo* structuring inequities (1, 125, 126), both positions point to the need to transcend biologism and individualism in health, but they also reduce the social to the human domain. However, some approaches to One Health show that reducing social relations to humans is misleading (23, 52, 127), whereas biopolitics and sociology set background to think a more-than-human social determination of health (9–11, 30, 128–130).

In the WHO's conceptual framework, structural determinants create health inequities through intermediary determinants (3). The structural determinants refer to the mechanisms by which political, economic, and social contexts generate "hierarchies of power, prestige, and access to resources" (3). The intermediary determinants are material and psychosocial circumstances, behavioral and biological factors, and the health system itself; they are a consequence of individuals' hierarchical positions. They are also the cause of exposures and vulnerabilities leading to health inequities (3).

Social cohesion and social capital are considered as both structural and intermediary determinants while the health state affects individuals' opportunities and thus feedback into the hierarchical structure (3). In short, it is a conceptual framework of causal nature where structural determinants have a position of precedence and prominence. The identification and measurement of the hypothetical effect of causal factors inform decision-making to reduce health inequities.

The social determination of health theorized in Latin America is not synthesized in a single reference. However, a common feature of different perspectives is that social determination is a category of critical analysis (1, 2, 131, 132). According to Samaja, social determination is a historical and ongoing process through which social hierarchy levels are "self-produced and reproduced, generating tensions and conflicts that motivate actions of restoration and transformation" (132) [translation is mine]. A given hierarchical level *reproduces* itself as a whole, regulating its parts (levels subsumed by it) to maintain the whole structure (132). However, the regulation is not absolute, and the relative autonomy of the parts is a source of change that *produces* new wholes (levels subsuming them) (132).

In this dialectic movement between regulation and relative autonomy, healthy and unhealthy forces configure epidemiologic profiles characteristic of the different hierarchical levels and positions within the levels (131). For instance, the family is one of such levels. The relative autonomous lifestyles of family members, as well as the regulations from higher social organization levels (community, political-administrative territorial divisions, contractual associations, and other institutions), determine their epidemiologic profile.

Despite fundamental differences between the two conceptual frameworks, they intersect at two points. Both identify a structural dimension (socioeconomic and political context in the social determinants; social production and reproduction in the social determination) and the ensuing hierarchy that imposes constraints on individuals according to their hierarchical position. Both point to the triple inequity of health determined by class, gender, and race/ethnicity.

One Health of Peripheries also intersects these points. The first from a biopolitical perspective in which the political is neither an external precursor of hierarchies nor an instrument monopolized by the most privileged hierarchical levels. The political is the relationships among individuals, the hierarchical order itself, it is realized and not owned, it is the foucauldian micro-physics of power (133) involving animals. Therefore, One Health of Peripheries participates in the second intersection in its theorizing of multispecies forms of health inequity.

Structural One Health is another helpful reference that goes beyond proximate causes to explore the crucial role of agribusiness in the production of zoonoses and pandemics through circuits of capital (52). However, it is worth noting that structural One Health and One Health of Peripheries differ. First, there is a difference of scope because One Health of Peripheries extends beyond infectious diseases. Second, structural One Health stresses more extensive empirical causal processes, whereas One Health of Peripheries agree with the need for more comprehensive causal explanations but stresses dialectical process to overcome the limitation of causal reasoning and empirical evidence. Third, power relations and health inequities are explicit multispecies phenomena in One Health of Peripheries. It is beyond the scope of this paper to explore the details of the (eco)social determination of One Health of Peripheries, so I will leave that for future works.

FIELD OF PRAXIS

Field and habitus are bourdieusian concepts incorporated in collective health. From them, we can think about health practices and knowledge as elaborated by subjects conditioned by symbolic structures like language and culture that allow and shape their representations and actions. Therefore, health is for health practitioners what they can know about it, so transforming the conditions that make knowledge possible changes health. In other words, the transformation of symbolic structures is also a health practice and affects health.

Practices are produced, perceived, and appreciated by *habitus*, a system of schemes "constituted in the course of collective history and acquired [and transformed] in the course of individual history" (8, 134) [translation is mine]. Individuals' *habitus* depends on hierarchies, so individual's perceptions, knowledge, and practices reveal their position and shape their relationships with individuals in other hierarchical places.

The field is the social space constituted by hierarchical relationships that condition the *habitus* and gain from this its meaning and value (135). In the filed, cooperation and conflict preserve or transform hierarchies. The most privileged positions have more capital—economic, cultural, social, and symbolic—to shape and legitimize hierarchies according to their interests. These interests are not necessarily conscious because, as part of the *habitus*, they are inculcated in "institutionalized spaces (family, school) by specialized agents who impose arbitrary norms using disciplinary techniques" (8) [translation is mine].

Peripheral positions "intervene as a passive, contrasting reference point" (8) [translation is mine]. Here is again the contrasting position of animals; those who want more capital to fight and legitimize their interests need a "social promotion experienced as an ontological transformation or as a process of civilization, a leap from nature to culture, from animality to humanity" (8) [translation is mine]. Thus, our relationships with animals are among the conditions of possibility of the habitus we acquire, and this, in turn, gives meaning and value to multispecies assemblages.

Depending on the *habitus* and the field, one will see, among others, unfitted mads who deserve their misfortunes, or psychiatric patients who can become more productive when receiving treatments provided by the pharmaceutical industry, or unhealthy exploitation regimes by way of progress. One will see pests and reservoirs of infectious agents that threaten public health, or multispecies collectives that share susceptibilities, in need of comprehensive health policies. Therefore, what enters into the health field and the way it enters is a social process.

Health practice is not neutral and can reinforce inequities. On the contrary, promoting One Health of Peripheries is an explicit commitment to reduce more-than-human inequities. Thus, the field of practice for such promotion is more specific; it is a field of praxis. Here I take praxis from Paulo Freire as reflexive action against oppression, toward liberation (136). Praxis as action informed by knowledge about the pathological effects of marginalization, and knowledge built on actions against marginalization.

In the field of collective health, there is extensive reference to "health promotion" and "life preservation" (137), non-anthropocentric perspectives (1), and "diversity of objects and theoretical discourses, without recognizing any hierarchical and evaluative perspective about them" (138) [translation are mine]. However, any generic reference to life or health is systematically pointed to the human, overlooking that life and health are more-than-human. This is a blind spot of collective health, brought to light by the praxis of One Health of Peripheries.

As a subfield of health, collective health does not need to cover everything that concerns health, and in this sense, it could be limited to the human. However, if collective health is transdisciplinary (139), concerned with the social determination of health (1) and aims at the "production of an expanded knowledge of health" (140) [translation is mine] it should promote One Health of Peripheries.

CONCLUSION

One Health of Peripheries is experience, understanding, and transformation to improve the wellness of marginalized multispecies collectives. One Health of Peripheries is about breaking margins to pursue multispecies justice.

Biopolitics and other critical perspectives offer conceptual tools to understand why marginalizing apparatuses determine most of the burden of ill-health and why we need multispecies intersectionality to achieve equitable alternatives.

Biological solutions stripped from the more-than-human social reality will not solve the remarkable challenges posed by mainstream One Health. Indeed, insisting on supposed apolitical and non-ideological epidemiologic settings of transmissible and physiopathological processes is part of the problem, just as pretending that all we need is a strong pharmaceutical industry supported by patents, intersectoral collaborations between "symmetrical" parties, and good deeds of the global North toward the global South.

The social determination of health is a comprehensive framework to embrace health complexity. However, it has a blind spot: One Health of Peripheries. The anthropocentrism of collective health perpetuates marginalization and limits the reach of health promotion.

One Health of Peripheries takes advantage of more-than-human biopolitics, One Health, collective health, and other sources of knowledge to inform the commitment of taking multispecies collectives out of peripheries. Such diversity inevitably incorporates theoretical difficulties.

It is worth noting that I am talking about One Health *of* Peripheries instead of One Health *on* Peripheries. That makes the commitment stronger as it is not purported to be a top-down endeavor. As a side comment, it was working *with* communities in favelas that I felt the need for a different theoretical background. Thus, I ended up trying to give sense to One Health of Peripheries.

The plurality of (academic, popular, and traditional) knowledge and the decolonial commitment of One Health of Peripheries need an explicit agenda. In another paper, we frame colonial apparatuses of marginalization, elaborate on how the epistemologies of the South are suitable to work with plural knowledge, and propose seven actions to promote One Health of Peripheries (18).

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

FUNDING

Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES, Coordination for the Improvement of Higher Education Personnel).

ACKNOWLEDGMENTS

I am grateful to the multispecies community of the São Remo favela (São Paulo, Brazil). At the University of São Paulo, I acknowledge the One Health of Peripheries network (Saúde

Única em Periferias – SUP-USP) and the Research group on Peripheries (nPeriferias-IEA-USP). I especially acknowledge Professor Flavia Mori Sarti for her comments to improve the reading of the paper.

REFERENCES

1. Breilh J. La determinación social de la salud como herramienta de transformación hacia una nueva salud pública (salud colectiva). *Rev Fac Nac Salud Pública.* (2013) 31:13–27.
2. Breilh J. *Critical Epidemiology and the Peoples' Health*. New York, NY: Oxford University Press (2021).
3. Solar O, Irwin A. *A Conceptual Framework for Action on the Social Determinants of Health*. Geneva: World Health Organization (2007).
4. Foucault M. *Power/Knowledge: Selected Interviews and Other Writings, 1972–1977. Translated by Colin Gordon, Leo Marshall, John Mepham, and Kate Soper*. Gordon C, editor. New York, NY: Pantheon (1980).
5. Agamben G. *What is an Apparatus? Translated by Kishik D, Pedatella S*. Stanford: Stanford University Press (2009).
6. Vieira-da-Silva LM. *O campo da saúde coletiva: gênese, transformações e articulações coma reforma sanitária*. Salvador: Editora da UFBA, Editora Fiocruz (2018).
7. Osmo A, Schraiber LB. The field of Collective Health: definitions and debates on its constitution. *Saude e Soc.* (2015) 24:201–14. doi: 10.1590/s0104-12902015s01018
8. Guerra Manzo E. Las teorías sociológicas de Pierre Bourdieu y Norbert Elias: los conceptos de campo social y habitus. *Estud Sociológicos.* (2010) 28:383–409.
9. Bujok M. Animals, women and social hierarchies: reflections on power relations. *Deport esuli, profughe.* (2013) 23:23–47.
10. Sayes E. Actor-Network Theory and methodology: Just what does it mean to say that nonhumans have agency? *Soc Stud Sci.* (2014) 44:134–49. doi: 10.1177/0306312713511867
11. Pyyhtinen O. *More-than-Human Sociology: A New Sociological Imagination*. New York, NY: Palgrave Macmillan (2016).
12. Haraway D. *Staying With the Trouble. Making Kin in the Chtulucene*. Durham and London: Duke University Press (2016).
13. Nussbaum M. *Frontiers of Justice: Disability, Nationality and Species Membership*. Cambridge: Harvard University Press (2003).
14. Almeida-Filho N. Modelos de determinação social das doenças crônicas não-transmissíveis. *Cien Saude Colet.* (2004) 9:865–84. doi: 10.1590/S1413-81232004000400009
15. Blattner CE, Coulter K, Kymlicka W. *Animal Labour: A New Frontier of Interspecies Justice?* Oxford: Oxford University Press (2020).
16. WHO, OIE, FAO. *Taking a Multisectoral, One Health Approach: A Tripartite Guide to Addressing Zoonotic Diseases in Countries*. Geneva: WHO, OIE, FAO (2019).
17. OIE. *World Organization for Animal Health: One Health*. (2020) Available online at: https://www.oie.int/en/for-the-media/onehealth/ (accessed February 7, 2020).
18. Baquero OS, Benavidez Fernández MN, Acero Aguilar M. From modern planetary health to decolonial promotion of one health of peripheries. *Front Public Health*. (2021) 9:637897. doi: 10.3389/fpubh.2021.637897
19. Davis A, Sharp J. Rethinking one health: emergent human, animal and environmental assemblages. *Soc Sci Med.* (2020) 258:113093. doi: 10.1016/j.socscimed.2020.113093
20. Friese C, Nuyts N. Posthumanist critique and human health: how nonhumans (could) figure in public health research. *Crit Public Health.* (2017) 27:303–13. doi: 10.1080/09581596.2017.1294246
21. Rock MJ. Who or what is 'the public' in critical public health? Reflections on posthumanism and anthropological engagements with One Health. *Crit Public Health.* (2017) 27:314–24. doi: 10.1080/09581596.2017.1288287
22. Nading AM. Humans, animals, and health: from ecology to entanglement. *Environ Soc.* (2013) 4:60–78. doi: 10.3167/ares.2013.040105
23. Craddock S, Hinchliffe S. One world, one health? Social science engagements with the one health agenda. *Soc Sci Med.* (2015) 129:1–4. doi: 10.1016/j.socscimed.2014.11.016
24. Brown H, Nading AM. Introduction: human animal health in medical anthropology. *Med Anthropol Q.* (2019) 33:5–23. doi: 10.1111/maq.12488
25. Lainé N, Morand S. Linking humans, their animals, and the environment again: a decolonized and more-than-human approach to "One Health." *Parasite.* (2020) 27:55. doi: 10.1051/parasite/2020055
26. Santos B de S, Meneses MP. *Epistemologias do Sul*. Sáo Paulo: Cortez Editora (2010).
27. Canclini NG. *Culturas Híbridas: estratégias para entrar e sair da modernidade. Translated by Ana Regina Lessa and Heloísa Pezza Cintrão*. Sáo Paulo: Edusp (2019).
28. Agamben G. *Homo sacer: sovereign power and bare life. Translated by Daniel Heller-Roazen*. Standford: Stanford University Press (1998).
29. Asdal K, Druglito T, Hinchliffe S. *Humans, Animals and Biopolitics: The More-than-Human Condition*. Asdal K, Druglito T, Hinchliffe S, editors. New York, NY: Roudlege (2016).
30. Wolfe C. *Before the Law: Humans and Other Animals in a Biopolitical Frame*. Chicago: The University of Chicago Press (2013).
31. Bazzicalupo L. *Biopolítica: Um mapa conceitual. Translated by Carlos Alberto Gianotti*. Sao Leopoldo: Editora Unisinos (2017).
32. Chrulew M, Wadiwel DJ. *Foucault and Animals*. Chrulew M, Wadiwel DJ, editors. Leiden: Brill (2016).
33. Esposito R. *Immunitas: The Protection and Negation of Life. Translated by Timothy Campbell*. Minneapolis: Polity (2011).
34. Esposito R. *Bios: Biopolitics and philosophy. Translated by Timothy Campbell*. Minneapolis: Univiersity of Minesota Press (2008).
35. Foucault M. *The Birth of Biopolitics: Lectures at the Collège de France, 1978–1979. Translated by Graham Burchell*. Senellart M, editor. London: Palgrave Macmillan (2010).
36. Lemke T. *Biopolitics: An advanced introduction. Translated by Eric Frederick Trump*. New York, NY: New York University Press (2011).
37. Mackenzie R. "Bestia sacer and agamben's anthropological machine: biomedical/legal taxonomies as somatechnologies of human and nonhuman animals' ethico-political relations. In: *Law and Anthropology*. New York, NY: Oxford University Press (2010).
38. Foucault M. *Discipline and Punish: The Birth of the Prison. Translated by Alan Sheridan*. New York, NY: Vintage (1995).
39. Foucault M. *The Archaeology of Knowledge. Translated by Alan Sheridan*. New York, NY: Pantheon (1972).
40. Pugliese J. Terminal truths: foucault's animals and the mask of the beast. In: *Foucault and Animals*. Chrulew M, Wadiwel DJ, editors. Leiden: Brill (2017). p. 17–36.
41. Derrida J. *The Animal That Therefore I Am. Translated by David Wills*. Mallet M-L. New York, NY: Fordham University Press (2008).
42. Diamond J. *Guns, Germs, and Steel: The Fates of Human Societies*. New York, NY: W. W. Norton & Company (2017).
43. Flannery K, Marcus J. *The Creation of Inequality: How Our Prehistoric Ancestors Set the Stage for Monarchy, Slavery, and Empire*. Cambridge: Harvard University Press (2012).
44. Wadiwel DJ. *The War Against Animals*. Leiden: Brill (2015).
45. Smithers G. *Slave Breeding: Sex, Violence, and Memory in African American History*. Gainesville: University Press of Florida (2012).
46. Camacho J. Los criaderos de esclavos: medicina, cuerpos y sexualidad en los ingenios de Cuba. *Hispanófila*. (2020) 188:3–18.
47. Ford H. *My Life and Work, in Collaboration With Samuel Crowthe*. New York, NY: Doubleday, Page & Company (1922).
48. Patterson C. *Eternal Treblinka: Our treatment of animals and the Holocaust*. New York, NY: Lantern Books (2002).
49. Wildlife Conservation Society. A Statement from the Wildlife Conservation Society. *WCSNewsroom*. (2020) Available online at: https://newsroom.wcs.org/News-Releases/articleType/ArticleView/articleId/14648/A-Statement-from-the-Wildlife-Conservation-Society.aspx (accessed November 7, 2020).

50. Quandt SA, Arcury-Quandt AE, Lawlor EJ, Carrillo L, Marín AJ, Grzywacz JG, et al. 3-D jobs and health disparities: the health implications of latino chicken catchers' working conditions. *Am J Ind Med.* (2013) 56:206–15. doi: 10.1002/ajim.22072
51. Crenshaw K. Mapping the margins: intersectionality, identity politics, and violence against women of color. *Stanford Law Rev.* (1991) 43:1241. doi: 10.2307/1229039
52. Wallace RG, Bergmann L, Kock R, Gilbert M, Hogerwerf L, Wallace R, et al. The dawn of Structural one health: a new science tracking disease emergence along circuits of capital. *Soc Sci Med.* (2015) 129:68–77. doi: 10.1016/j.socscimed.2014.09.047
53. Shereen MA, Khan S, Kazmi A, Bashir N, Siddique R. COVID-19 infection: origin, transmission, and characteristics of human coronaviruses. *J Adv Res.* (2020) 24:91–8. doi: 10.1016/j.jare.2020.03.005
54. Wolfe ND, Dunavan CP, Diamond J. Origins of major human infectious diseases. *Nature.* (2007) 447:279–83. doi: 10.1038/nature05775
55. Nii-Trebi NI. Emerging and neglected infectious diseases: insights, advances, and challenges. *Biomed Res Int.* (2017) 2017:5245021. doi: 10.1155/2017/5245021
56. WHO. *Neglected tropical diseases*. (2019). Available online at: https://www.who.int/neglected_diseases/diseases/en/ (accessed June 22, 2019).
57. WHO. *Ending the Neglect to Attain the Sustainable Development Goals: A Road Map for Neglected Tropical Diseases 2021-2030*. Geneva: World Health Organization (2020).
58. European Parliament and of the Council of the European Union. Regulation (EU) 2021/522 of the European Parliament and of the Council of 24 March 2021 establishing a Programme for the Union's action in the field of health ("EU4Health Programme") for the period 2021–2027, and repealing Regulation (EU) No 282/2014 (Tex. *Off J Eur Union*. (2021) 107:1–29.
59. Kirksey SE, Helmreich S. The emergence of multispecies ethnography. *Cult Anthropol*. (2010) 25:545–76. doi: 10.1111/j.1548-1360.2010.01069.x
60. Guerrero R, Margulis L, Berlanga M. Symbiogenesis: the holobiont as a unit of evolution. *Int Microbiol.* (2013) 16:133–43. doi: 10.2436/20.1501.01.188
61. Krenak A. *Ideias para adiar o fim do mundo*. Sáo Paulo: Companhia das Letras (2019).
62. Latour B. *We Have Never Been Modern. Trans. C. Porter. Hemel Hampstead, Harvester Wheatsheaf*. Cambridge: Harvard University Press (2012).
63. Leff E. Agroecologia e saber ambiental. *Agroecol e Desenvolv Rural sustentável.* (2002) 3:36–51.
64. Wezel A, Bellon S, Doré T, Francis C, Vallod D, David C. Agroecology as a science, a movement and a practice. A review. *Agron Sustain Dev*. (2009) 29:503–15. doi: 10.1051/agro/2009004
65. Hinchliffe S, Whatmore S. Living cities: towards a politics of conviviality. *Sci Cult.* (2006) 15:123–38. doi: 10.1080/09505430600707988
66. Houston D. Urban re-generations: afterword to special issue on the politics of urban greening in Australian cities. *Aust Geogr*. (2020) 51:257–63. doi: 10.1080/00049182.2020.1783743
67. Rotherham I. *Recombinant Ecology—A Hybrid Future?* Springer: Sheffield (2017).
68. Baquero OS, Queiroz MR. Size, spatial and household distribution, and rabies vaccination coverage of the Brazilian owned-dog population. *Transbound Emerg Dis.* (2019) 66:1693–700. doi: 10.1111/tbed.13204
69. IBGE. *Pesquisa Nacional por Amostra de Domicílios—Síntese de indicadores*. Rio de Janeiro: IBGE (2013).
70. Ascione FR. Children who are cruel to animals: a review of research and implications for developmental psychopathology. *Anthrozoos A Multidiscip J Interact People Anim.* (1993) 6:226–47. doi: 10.2752/089279393787002105
71. Ascione FR, Weber CV, Thompson TM, Heath J, Maruyama M, Hayashi K. Battered pets and domestic violence animal abuse reported by women experiencing intimate violence and by nonabused women. *Violence Against Women.* (2007) 13:354–73. doi: 10.1177/1077801207299201
72. Baldry AC. Animal abuse and exposure to interparental violence in italian youth. (2003) 18:258–81. doi: 10.1177/0886260502250081
73. Flynn CP. Examining the links between animal abuse and human violence. *Crime, Law Soc Chang.* (2011) 55:453–68. doi: 10.1007/s10611-011-9297-2
74. Gullone E. *Animal Cruelty, Antisocial Behaviour and Aggression More than a Link*. Hampshire: Palgrave Macmillan (2012).
75. Allen M, Gallagher B, Jones B. Domestic violence and the abuse of pets: researching the link and its implications in Ireland. *Practice.* (2006) 18:167–81. doi: 10.1080/09503150600904060
76. Faver CA, Strand EB. To Leave or to Stay? *J Interpers Violence.* (2003) 18:1367–77. doi: 10.1177/0886260503258028
77. Faver CA, Strand EB. Fear, guilt, and grief: harm to pets and the emotional abuse of women. *J Emot Abus.* (2007) 7:51–70. doi: 10.1300/J135v07n01_04
78. Newberry M. Pets in danger: exploring the link between domestic violence and animal abuse. *Aggress Violent Behav.* (2017) 34:273–81. doi: 10.1016/j.avb.2016.11.007
79. Upadhya V. Abuse of animals as a method of domestic violence: the need for criminalization. *Emory Law J.* (2013) 23:1163. doi: 10.2139/ssrn.2251994
80. Baquero OS, Ferreira F, Robis M, Neto JSF, Onell JA. Bayesian spatial models of the association between interpersonal violence, animal abuse and social vulnerability in São Paulo, Brazil. *Prev Vet Med.* (2018) 152:48–55. doi: 10.1016/j.prevetmed.2018.01.008
81. Bourgois P. In search of masculinity: violence, respect and sexuality among Puerto Rican crack dealers in east Harlem. *Br J Criminol.* (1996) 36:412–27. doi: 10.1093/oxfordjournals.bjc.a014103
82. Burke JG, O'Campo P, Peak GL. Neighborhood influences and intimate partner violence: does geographic setting matter? *J Urban Heal.* (2006) 83:182–94. doi: 10.1007/s11524-006-9031-z
83. Cunradi CB, Caetano R, Clark C, Schafer J. Neighborhood poverty as a predictor of intimate partner violence among white, black, and hispanic couples in the united states: a multilevel analysis. *Ann Epidemiol.* (2000) 10:297–308. doi: 10.1016/S1047-2797(00)00052-1
84. Evans GW, English K. The environment of poverty: multiple stressor exposure, psychophysiological stress, and socioemotional adjustment. *Child Dev*. (2002) 73:1238–48. doi: 10.1111/1467-8624.00469
85. Faver CA. School-based humane education as a strategy to prevent violence: review and recommendations. *Child Youth Serv Rev*. (2010) 32:365–70. doi: 10.1016/j.childyouth.2009.10.006
86. Sprinkle JE. Animals, empathy, and violence. *Youth Violence Juv Justice.* (2008) 6:47–58. doi: 10.1177/1541204007305525
87. IBGE. Censo demográfico 2010—Aglomerados subnormais. Rio de Janeiro: IBGE (2011).
88. UN-Habitat. *World Cities Report 2016*. UN-Habitat (2016).
89. Ezeh A, Oyebode O, Satterthwaite D, Chen Y-F, Ndugwa R, Sartori J, et al. The health of people who live in slums 1 The history, geography, and sociology of slums and the health problems of people who live in slums. *Lancet.* (2017) 389:547–58. doi: 10.1016/S0140-6736(16)31650-6
90. Schmidt PL. Companion animals as sentinels for public health. *Vet Clin North Am Small Anim Pract.* (2009) 39:241–50. doi: 10.1016/j.cvsm.2008.10.010
91. Pastorinho R, Sousa AC. *Pets as Sentinels, Forecasters and Promoters of Human Health*. Cham: Springer (2020).
92. Labrecque J, Walsh CA. Homeless women's voices on incorporating companion animals into shelter services. *Anthrozoos.* (2011) 24:79–95. doi: 10.2752/175303711X12923300467447
93. Toylor H, Williams P, Gray D. Homelessness and dog ownership: an investigation into animal empathy, attachment, crime, drug use, health and public opinion. *Anthrozoos.* (2004) 17:353–68. doi: 10.2752/089279304785643230
94. Irvine L. *My Dog Always Eats First: Homeless People and Their Animals*. Boulder: Lynne Rienner (2015).
95. Singer RS, Hart LA, Zasloff RL. Dilemmas associated with rehousing homeless people who have companion animals. *Psychol Rep.* (1995) 77:851–7. doi: 10.2466/pr0.1995.77.3.851
96. Sakelaropoulos K, Davey B, Knight M. *Pets and Homeless People in Nottingham. People Anim Together Heal.* (1998).
97. United Nations Development Programme. Goal 2: Zero hunger. *Sustain Dev Goals* Available online at: https://www.undp.org/content/undp/en/home/sustainable-development-goals/goal-2-zero-hunger.html (accessed May 5, 2020).
98. IPCC. *Summary for policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of*

the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press (2014).

99. IPCC. *Technical Summary. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press (2013).
100. Reisinger A, Clark H. How much do direct livestock emissions actually contribute to global warming? *Glob Chang Biol.* (2018) 24:1749–61. doi: 10.1111/gcb.13975
101. Bento CB, Filoso S, Pitombo LM, Cantarella H, Rossetto R, Martinelli LA, et al. Impacts of sugarcane agriculture expansion over low-intensity cattle ranch pasture in Brazil on greenhouse gases. *J Environ Manage.* (2018) 206:980–8. doi: 10.1016/j.jenvman.2017.11.085
102. McMahon BJ, Morand S, Gray JS. Ecosystem change and zoonoses in the Anthropocene. *Zoonoses Public Health.* (2018) 65:755–65. doi: 10.1111/zph.12489
103. Pimm SL, Jenkins CN, Abell R, Brooks TM, Gittleman JL, Joppa LN, et al. The biodiversity of species and their rates of extinction, distribution, and protection. *Science.* (2014) 344:1246752. doi: 10.1126/science.1246752
104. World Bank Group. Rethinking the Path to Inclusion, Growth and Sustainability. Brazil Systematic Country Diagnostic. (2016). Available online at: http://documents.worldbank.org/curated/pt/239741467991959045/pdf/106569-SCD-P151691-PUBLIC-non-board-version.pdf (accessed June 14, 2021).
105. Cassidy ES, West PC, Gerber JS, Foley JA. Redefining agricultural yields: from tonnes to people nourished per hectare. *Environ Res Lett.* (2013) 8:1–8. doi: 10.1088/1748-9326/8/3/034015
106. Ministério do Desenvolvimento Regional do Brasil. SNIS—PAINEL DE INFORMAÇÕES SOBRE SANEAMENTO. Available online at: http://www.snis.gov.br/painel-informacoes-saneamento-brasil/web/painel-setor-saneamento (accessed May 5, 2020).
107. Alavanja MCR, Samanic C, Dosemeci M, Lubin J, Tarone R, Lynch CF, et al. Use of agricultural pesticides and prostate cancer risk in the agricultural health study cohort. *Am J Epidemiol.* (2003) 157:800–14. doi: 10.1093/aje/kwg040
108. Pereira R, Simmons C, Walker R. Smallholders, agrarian reform, and globalization in the brazilian amazon: cattle versus the environment. *Land.* (2016) 5:24. doi: 10.3390/land5030024
109. Neo H, Emel J. *Geographies of Meat: Politics, Economy and Culture*. Abingdon: Routledge (2017).
110. Martin P, Jackson-Smith D. *Immigration and Farm Labor in the U.S.* National Agricultural & Rural Development Policy Center (2013).
111. Ramos A, Carlo G, Grant K, Trinidad N, Correa A. Stress, Depression, and Occupational Injury among Migrant Farmworkers in Nebraska. *Safety.* (2016) 2:23. doi: 10.3390/safety2040023
112. Koutros S, Silverman DT, Alavanja MC, Andreotti G, Lerro CC, Heltshe S, et al. Environmental exposures and cancer occupational exposure to pesticides and bladder cancer risk. *Int J Epidemiol.* (2016) 45:792–805. doi: 10.1093/ije/dyv195
113. Abdi H, Lee J, Ellison G, Lai G, Lam T. Abstract 2300: pesticides and primary liver cancer: a systematic review and meta-analysis. *Cancer Res.* (2017) 77:2300. doi: 10.1158/1538-7445.AM2017-2300
114. Von Essen SG, Auvermann BW. Health effects from breathing air near CAFOs for feeder cattle or hogs. *J Agromed.* (2005) 10:55–64. doi: 10.1300/J096v10n04_08
115. Heederik D, Sigsgaard T, Thorne PS, Kline JN, Avery R, Bønløkke JH, et al. Health effects of airborne exposures from concentrated animal feeding operations. *Environ Health Perspect.* (2007) 115:298–302. doi: 10.1289/ehp.8835
116. Schultz AA, Peppard P, Gangnon RE, Malecki KMC. Residential proximity to concentrated animal feeding operations and allergic and respiratory disease. *Environ Int.* (2019) 130:104911. doi: 10.1016/j.envint.2019.104911
117. Silbergeld EK, Graham J, Price LB. Industrial food animal production, antimicrobial resistance, and human health. *Annu Rev Public Health.* (2008) 29:151–69. doi: 10.1146/annurev.publhealth.29.020907.090904
118. Cho SH, Lim YS, Kang YH. Comparison of antimicrobial resistance in escherichia coli strains isolated from healthy poultry and swine farm workers using antibiotics in Korea. *Osong Public Heal Res Perspect.* (2012) 3:151–5. doi: 10.1016/j.phrp.2012.07.002
119. Huang E, Gurzau AE, Hanson BM, Kates AE, Smith TC, Pettigrew MM, et al. Detection of livestock-associated methicillin-resistant Staphylococcus aureus among swine workers in Romania. *J Infect Public Health.* (2014) 7:323–32. doi: 10.1016/j.jiph.2014.03.008
120. Rinsky JL, Nadimpalli M, Wing S, Hall D, Baron D, Price LB, et al. Livestock-associated methicillin and multidrug resistant staphylococcus aureus is present among industrial, not antibiotic-free livestock operation workers in North Carolina. *PLoS ONE.* (2013) 8:e67641. doi: 10.1371/journal.pone.0067641
121. Fitzgerald AJ, Kalof L, Dietz T. Slaughterhouses and increased crime rates. *Organ Environ.* (2009) 22:158–84. doi: 10.1177/1086026609338164
122. Singer P. *Animal Liberation: The Definite Classic of Animal Movement*. New York, NY: Harper Perennial Modern Classics (2009).
123. Robbins JA, Franks B, Weary DM, Von Keyserlingk MAG. Awareness of ag-gag laws erodes trust in farmers and increases support for animal welfare regulations. *Food Policy.* (2016) 61:121–5. doi: 10.1016/j.foodpol.2016.02.008
124. ASPCA. What Is Ag-Gag Legislation? *Farm Anim Welf.* Available online at: https://www.aspca.org/animal-protection/public-policy/what-ag-gag-legislation (accessed May 5, 2020).
125. da Rocha PR, Leal David HMS. Determination or determinants? A debate based on the theory on the social production of health. *Rev da Esc Enferm.* (2015) 49:129–35. doi: 10.1590/S0080-623420150000100017
126. Garbois JA, Sodré F, Dalbello-Araujo M. Da noção de determinação social à de determinantes sociais da saúde. *Saúde em Debate.* (2017) 41:63–76. doi: 10.1590/0103-1104201711206
127. Rock MJ, Degeling C. Toward one health promotion. In: *A Companion to the Anthropology of Environmental Health*. Singer M, editor. Chichester: Wiley-Blackwell. p. 68–82.
128. Keck F. A genealogy of animal diseases and social anthropology (1870–2000). *Med Anthropol Q.* (2019) 33:24–41. doi: 10.1111/maq.12442
129. Peggs K. *Animals and Sociology*. London: Palgrave Macmillan (2012).
130. Tuomivaara S. *Animals in the Sociologies of Westermarck and Durkheim*. London: Palgrave Macmillan (2019).
131. Breilh J. *Epidemiologia crítica: ciência emancipadora e intercultural. Translated by Vera Ribeiro*. Rio de Janeiro: Editora Fiocruz (2006).
132. Samaja J. *Epistemología de la salud: reproducción social, subjetividad y transdisciplina*. Buenos Aires: Lugar (2007).
133. Foucault M. *Microfísica do Poder. Organização, introdução e revisão técnica de Renato Machado.* 26th ed. Sáo Paulo: Graal (2013).
134. Bourdieu P. *Intelectuales, política y poder. Translation by Alicia Gutierrez*. Buenos Aires: Eudeba (2002).
135. Bourdieu P. *Habitus and Field: General Sociology, Volume 2 (1982–1983). Translation by Peter Collier*. Cambridge: Polity (2019).
136. Freire P. *Pedagogy of the oppressed. Translated by Myra Bergman Ramos.* New York, NY: Bloomsbury (2014).
137. Campos GW de S. Saúde pública e saúde coletiva: campo e núcleo de saberes e práticas. *Cien Saude Colet.* (2000) 5:219–230. doi: 10.1590/S1413-81232000000200002
138. Birman J. A physis da saúde coletiva. *Physis Rev Saúde Coletiva.* (1991) 1:7–11. doi: 10.1590/S0103-73311991000100001
139. Almeida Filho N de. Transdisciplinaridade e Saúde Coletiva. *Cien Saude Colet*. (1997) 2:5–20. doi: 10.1590/1413-812319972101702014
140. de Souza LEPF. Saúde Pública ou Saúde Coletiva? *Rev Espaço para a saúde.* (2014) 15:7–21 doi: 10.22421/1517-7130.2014v15n4p7

Conflict of Interest: The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

ORIGINAL RESEARCH
published: 23 July 2021
doi: 10.3389/fpubh.2021.644786

Knowledge, Attitudes, and Risk Perception Toward Avian Influenza Virus Exposure Among Cuban Hunters

Beatriz Delgado-Hernández[1], *Lourdes Mugica*[2], *Martin Acosta*[2], *Frank Pérez*[1,3], *Damarys de las Nieves Montano*[1], *Yandy Abreu*[1], *Joel Ayala*[1], *María Irian Percedo*[1] *and Pastor Alfonso*[1]*

[1] Epidemiology Group, National Center for Animal and Plant Health (CENSA), World Organisation for Animal Health (OIE) Collaborating Center for the Reduction of the Risk of Disaster in Animal Health, San José de las Lajas, Cuba, [2] Bird Ecology Group, Biology Faculty, Havana University, Vedado, Cuba, [3] Department of Veterinary Medicine, Faculty of Agricultural Sciences, University of Granma, Bayamo, Cuba

OPEN ACCESS

Edited by:
Alexander Welker Biondo,
Federal University of Paraná, Brazil

Reviewed by:
Henrik Lerner,
Ersta Sköndal University College, Sweden
Gary Vroegindewey,
Lincoln Memorial University, United States

***Correspondence:**
Pastor Alfonso
alfonso@censa.edu.cu

Specialty section:
This article was submitted to Planetary Health, a section of the journal Frontiers in Public Health

Received: 21 December 2020
Accepted: 28 June 2021
Published: 23 July 2021

Citation:
Delgado-Hernández B, Mugica L, Acosta M, Pérez F, Montano DdlN, Abreu Y, Ayala J, Percedo MI and Alfonso P (2021) Knowledge, Attitudes, and Risk Perception Toward Avian Influenza Virus Exposure Among Cuban Hunters. Front. Public Health 9:644786. doi: 10.3389/fpubh.2021.644786

A critical step for decreasing zoonotic disease threats is to have a good understanding of the associated risks. Hunters frequently handle potentially infected birds, so they are more at risk of being exposed to zoonotic avian pathogens, including avian influenza viruses (AIVs). The objective of the current study was to gain a better understanding of Cuban hunters' general hunting practices, focusing on their knowledge and risk perception on avian influenza. An anonymous and voluntary semi-structured questionnaire was designed and applied to 398 hunters. Multiple correspondence analyses found relationships with potential exposure of AIVs to people and domestic animals. The main associated risks factors identified were not taking the annual flu vaccine (60.1%) and not cleaning hunting knives (26.3%); Direct contact with water (32.1%), cleaning wild birds at home (33.2%); receiving assistance during bird cleaning (41.9%), keeping poultry at home (56.5%) and feeding domestic animals with wild bird leftovers (30.3%) were also identified as significant risk factors. The lack of use of some protective measures reported by hunters had no relationship with their awareness on avian influenza, which may imply a lack of such knowledge. The results evidenced that more effective risk communication strategies about the consequences of AIVs infecting human or other animals, and the importance of reducing such risks, are urgently needed.

Keywords: avian influenza, hunter, wild bird, risk perception, pandemic, One Health, Cuba

INTRODUCTION

Influenza A viruses (IAVs) are among the most challenging viruses that threaten both human and animal health (1). Their ability to transmit between different species and, to undergo genetic reassortments is extremely alarming (2). In fact, the best studied pandemic influenza viruses, like those of 1918, 1957, 1968, and 2009, ultimately acquired some or all of their gene segments from the avian IAV gene pool with swine origin genes also being present in some viruses (3).

Wild aquatic birds, especially birds in the orders Anseriformes (ducks and geese) and Charadriiformes (gulls and shorebirds) that migrate in large numbers from North America to Cuba, are considered natural hosts for most IAV subtypes (4, 5). In fact, the migratory nature of many waterfowl species, along with the potential persistence of avian influenza viruses (AIVs) in them, presents a potential route for global dissemination and spillover of these viruses (6, 7).

Individuals who are engaged in occupations requiring animal handling (hunting, butchering, etc.) or those working in agricultural areas or forests, are at increased risk of exposure to AIVs compared to the general population (8). Direct transmission of AIVs from wild birds to hunters, or anybody interacting with wildlife, might have at least two significant outcomes; a direct introduction of a novel virus that could be sustained by human-to-human transmission, or a possible reassortment event where avian genes could be incorporated into an existing seasonal human influenza strain (9).

Poultry keepers and wild bird hunters are considered at highest risk of contracting AIV infections (10). However, wild bird hunters are likely to be at highest risk considering the high number of people involved in hunting and the direct nature of their contact with dead wild birds and bird carcasses during cleaning. Furthermore, some duck species which are commonly hunted in Cuba are known to have the highest prevalence level for AIVs (4). Since AIVs are known to replicate in wild bird in the absence of overt signs of disease (11), it is possible that apparently healthy hunted birds could spread AIVs to the hunters.

In addition to the direct AIV exposure risk for hunters, they may also indirectly cause the dispersal of such viruses in the environment, with the possibility of spillover to other species. It is known that AIVs are able to infect a broad range of host species (5) include several mammals and poultry, on occasions with significant economic losses. Despite the fact that AIVs often exist in their wild bird reservoir host as low pathogenic viruses (12), when they infect poultry, they can evolve to cause serious disease termed highly pathogenic avian influenza (HPAI), with severe economic consequences (13). Since the poultry sector provides one of the most popular sources of animal protein around the world, owing to its affordability, nutritional value and lack of cultural restrictions, AIVs represent an important threat to food security. All these facts clearly demonstrate the need to address the associated risks from a "One Health" perspective (14).

Good knowledge, attitudes, and practices (KAPs) targeted toward certain diseases or infections among the public are essential for successful control and outbreak prevention of pandemics (15, 16). However, efforts to better define KAPs in hunters have been scarce, and mainly limited to Canada and the United States of America (17–19). Since, behaviors and risk attitudes can vary from country to country, studies in different countries where different practices are carried out are well-justified. The objective of the current study was to gain a better understanding of Cuban hunters' general harvesting practices, knowledge and risk perception on avian influenza (AI).

TABLE 1 | Variables related with knowledge, perception and risk attitudes used for analyses.

Variable	Kind of variable	Description
Knowledge about avian influenza	Knowledge	As a potential proxy for adopting protective measures
Wild bird hunting as risk for health	Knowledge	As a potential proxy for adopting protective measures
Water contact during hunting	Attitude	As a proxy for getting infection from water
Smoking	Attitude	As a proxy for getting infection through oral way with contaminated hands
Hunting with dogs	Attitude	As a proxy to reduce contact with water
Cleaning hunted birds at home	Attitude	As a proxy for AIV dissemination to new locations
Get assistance for birds cleaning	Attitude	As a proxy to expose additional individuals to virus infection
Sharing hunting knives with household uses	Attitude	As a proxy to contaminate food
Cleaning knives after hunting	Attitude	As a proxy for reducing risk of infection
Having backyard poultry at home	Attitude	As a proxy to propitiate AIV to evolve
Feed domestic animal with bird leftover	Attitude	As a proxy for spillover
Unvaccinated against flu	Protective	As a proxy for virus viral genome reassortments in case of coinfections
Washing hands during hunting	Protective	As a proxy for reducing risk infection

MATERIALS AND METHODS

Survey

A semi-structured questionnaire (see **Supplementary Material**) was designed taking into account related works on this subject (17, 18). The survey was validated by local knowledgeable hunting specialists ($n = 3$) and a small group of local wild bird hunters ($n = 5$). A total of 398 Cuban wild bird hunters were recruited to the study. The survey was conducted opportunistically taking advantage of planned meetings between 2016 and 2018 of the Sport Hunting Cuban Federation (FCCD), which has around 4,025 members (20). No information on avian influenza was provided to hunters before giving them the questionnaire. The surveys that were <50% completed were discarded. For statistical purposes, in the cases of incomplete surveys the proportions of the response were rescaled according to denominators of the completed answers.

Descriptive Analysis

The demographic variables were analyzed through descriptive statistics. The variables of age and experience of the hunter were categorized according to the median. Variables related with risk or knowledge (**Table 1**) were compared by proportion analysis with a confidence interval of 95% using the WINPEPI application (21) and a Wald Test in the CompaProp application (22). To evaluate the risk perception level about AI, a univariate and multivariate logistic regression were carried out with p-value < 0.05 using the SPSS v.21 program. For this analysis, hunters were categorized according to their hierarchic status (Hunters belonging to the FCCD Steering Committee vs. those only dedicated to hunting) within the Federation.

Multivariate Analysis

Multiple correspondence analysis (MCA) and hierarchical cluster analysis were executed using the *FactoMineR* package (23) through R v3.5. The variables with *p*-values higher than 0.05 were discarded. A minimum number of latent variables (or components) with linear combinations of the original variables that are independent from each other were defined (24). The number of dimensions in the analysis was selected according to the percentage of inertia.

MCA was also used in pre-processing to transform categorical variables into continuous ones in order to perform a cluster analysis by ascending hierarchical classification (Ward's method and Euclidean similarity distance between observations) (24, 25). Homogeneous subject profiles based on the MCA dimensions assuming that they have substantive coherence (24, 26) were defined. The coordinate distribution of MCA categories in a two-dimension space based in eigenvalues and the variable description by categories of clusters were combined for the result representation with Ggplot2 package in R v3.5. The variables: Knowledge about avian influenza, Wild bird hunting as risk for health, Age and Experience Categorized, and Hierarchic status were used as supplementary variables in the MCA and cluster analysis.

Ethical Approval

Participants were provided with information describing the study objectives and they were reassured that all responses would be anonymous.

Informed Consent

Verbal informed consent of willingness to participate in the study was obtained from each respondent before they filled in the questionnaire.

RESULTS

A total of 398 out of 403 (98.76%) surveys were valid from which 305 (76.63%) were completed in full. Of the valid surveys 17.83% belonged to hunters with coordination responsibilities at the provincial or national level in the FCCD. Among responders, only one was female. The number of hunting days/year and the number of hunted birds/year accounted for the higher variability in the descriptive analysis (**Table 2**). Ducks were hunted by 215 out of 252 (85.3%) of the surveyed hunters, of which 82 (38.14%) referred to the capture of Blue-winged teal (*Spatula discors)*.

The categorized variables formed two groups based on age and experience: young people (≤50 years) and older people (>50 years), as well as hunters (≤17 years) with little hunting experience and the most experienced hunters (>17 years).

Six groups were formed according to the proportion of the risk factors. Hygienic practices with knives (85%, CI95%:82–89%) and hands (86%, CI95%:81–88%), Water contact during hunting (77%, CI95%:73–81%), Knowledge about avian influenza (75%, CI95%:71–79%) and cleaning hunted birds at home (74%, CI95%:70–79%) were the questions with a greater proportion with affirmative replies. The questions related to hunter's attitudes (two last groups) had a lower proportion of positive answers (<50%) (**Table 3**).

TABLE 2 | Interquartile ranges of quantitative and demographic variables of wild bird hunters surveyed from 2016 to 2018 (Q1: quartile 25%, Q3: quartile 75%, IQR: interquartile range).

General variables	Minimum	Q1	Median	Q3	IQR	Maximum
Number of hunting days per year	1	30	40	80.25	50.25	240
Number of hunted birds per year	3	44	61	143	99	1,800
Quantity of hunting months per year	1	5	6	7	2	12
Hunter age	17	41	50	59	18	85
Hunting experience (years)	1	10	17	30	20	82

TABLE 3 | Relationship of risk attitudes and knowledge of Cuban hunters on avian influenza virus exposure.

Variable	Total answer	Proportion of affirmative replies (CI 95%)	Wald test significance
Washing hands after hunting	393	0.86 (0.822–0.893)	a
Cleaning knives after hunting	379	0.85 (0.810–0.884)	a
Water contact during hunting	396	0.77 (0.728–0.813)	b
Knowledge about avian influenza	393	0.75 (0.705–0.793)	b
Cleaning hunted birds at home	393	0.74 (0.697–0.786)	b
Flu unvaccinated against flu	393	0.64 (0.594–0.591)	c
Wild bird hunting as risk for health	394	0.59 (0.544–0.643)	c
Hunting with dog	397	0.58 (0.532–0.631)	c
Having backyard birds at home	388	0.48 (0.431–0.533)	d
Get assistance for bird cleaning	397	0.46 (0.414–0.514)	d
Sharing hunting knives with household uses	393	0.46 (0.405–0.506)	d
Feed domestic animal with birds leftover	387	0.38 (0.331–0.430)	e
Smoking	395	0.35 (0.307–0.404)	e

Proportions with different letters in Wald test differs according to the calculation of confidence intervals.
CI, confidence interval.

Eight out of 13 studied variables were significant ($p < 0.05$) in the univariate analysis (**Supplementary Table 1**). Of these eight variables, having backyard poultry at home and smoking were significant in the multivariate analysis with an odds ratio (OR) of 2.37 (CI 95%: 1.247–4.515) and 2.203 (CI 95%: 1.083–4.483), respectively, for the hunters with managerial responsibilities with respect to pure hunters (**Table 4**). However, these categories did not have any significant differences in knowledge on AI.

MCA and Hierarchical Cluster Analyses

A variability of 61.9% was observed for the four first dimensions in the MCA analysis of hunters' exposure to AIVs. The variables with the main contribution to the first dimension were: be unvaccinated against flu (60.1%), be a smoker (54.4%) and not cleaning hunting knives (26.3%). The variables of direct contact

TABLE 4 | Maximum likelihood estimates of multivariate regression function of variables derived from individual analyses between Manager hunters and Pure hunters.

Variable	B	SE	Wald	P	Odds ratio	95% CI for odds ratio
Feed domestic animal with birds leftover	0.613	0.336	3.331	0.068	1.846	0.956–3.566
Having backyard poultry at home	0.864	0.328	6.936	0.008	2.373	1.247–4.515
Smoking	0.790	0.362	4.751	0.029	2.203	1.083–4.483
Cleaning hunted birds at home	−0.885	0.446	3.925	0.048	0.413	0.172–0.991
Hunting with dog	−0.896	0.339	6.974	0.008	0.408	0.210–0.794
Knowledge about avian influenza	−1.401	0.548	6.533	0.011	0.246	0.084–0.721

B, estimated slope; S.E., standard error; Odds ratio: [Exp (B)].

with water (32.1%) and cleaning wild birds at home (33.2%) headed the second dimension. The third dimension included hunters that received assistance during bird cleaning (41.9%) and hunters who did not wash their hands (23%), while the fourth dimension was represented by people that used hunting knives in household activities (67.8%) and hunted with dogs (33.9%) (**Supplementary Table 2**).

The hunter's practices and/or attitudes that exposed them to AIVs were identified into the three groups (**Figure 1**). Most of the risk categories were within the first cluster whilst the second group was the smallest.

The inertia of two first dimensions was 62.66% for analysis of AIV exposure to domestic animals. The variables hunting with dog (56.4%), have poultry at home (56.5%) and feed domestic animals with bird leftover (30.3%) predominated in the first dimension. The transfer of hunted birds home for cleaning was the most represented variable in the second dimension (83%) (**Supplementary Table 3**).

According to hunter's behavior, four groups were obtained in the cluster analysis (**Figure 2**). Interestingly, hunters who did not clean birds at home didn't share characteristics with any of the other clusters. On the contrary, the first cluster showed a high potential risk of AIV exposure for domestic animals. The variables hunter age and hunting experience were not associated to the other variables.

DISCUSSION

This study targets the "first-line" people (wild bird hunters) who might both acquire infection with AIVs and expose domestic animals to them. Cuban hunters were found to have limited knowledge of avian influenza and associated risks which demands a more effective risk communication strategy to bridge the gaps between knowledge and practical actions.

The current investigation did not show a relation between knowledge on AI and the adoption of protective measures. Therefore, it is likely that the understanding on AI of the surveyed hunters could be rudimentary or insufficient to be translated into protective behaviors. However, this knowledge was greater in terms of the risk of exposure of AIV to domestic animals. This could be related to the fact that risk communication has been focused on the consequences of infection with AIVs for poultry, compared to infection of human. Another possible explanation for such differences is that effects might depend upon the specific type of knowledge measured (10).

Limited knowledge, low risk perception and inadequate protective behavior can increase the risk of infection with AIVs (10). However, differences between stated knowledge and practical knowledge are recognized (27). Most hunters were aware of AI but were not actively preventing the introduction and transmission of the virus as they perceived it as a low risk to their health, as described by Oruganti et al. (19). Likewise, other investigations show high AI knowledge levels but insufficient adoption of protective measures (10, 28). Just because hunters may know about a wildlife disease and how to prevent exposure to it does not imply they perceive a risk of exposure (19). The fact that knowledge about AI did not translate into protective behaviors was notable even within the subgroup of hunters with organizational responsibilities within the FCCD. This emphasizes the need for risk communication actions with emphasis on those in a position to play a more active role in the transfer of knowledge within the Federation.

Preventive measures such as hand washing and wearing masks are fundamental for counteracting influenza virus infection (29). The data on protective behaviors showed that washing hands was a standard practice. However, accessible water in wetlands may be contaminated with water-borne microorganisms. In particular, a study about the potential for avian-origin viruses to remain infective in North American wetlands for extended periods proved its viability at a mean temperature of 4.2–4.9°C (−0.1–22.9°C) (30). Given the lipid nature of the envelope of IAVs (29, 31) the most practical and effective method of decontamination during hunting is the use of alcohol gels as a disinfectant.

Consistent with other studies (10, 18, 32) washing hands and cleaning hunting utensils after finishing the activity were the most prevalent practices, which can reduce hunter's AIV exposure. Remarkably, inexperienced hunters who don't know about AI, practiced these activities less frequently, which highlight the importance of knowledge.

Knowledge about effective behaviors is particularly likely to enhance perceptions about efficacy of conducts, which have consistently been linked to precautionary practices (33). Nevertheless, knowledge alone is not enough to produce behavior changes because it depends of economic and social factors that enable or disable such change (10). Consequently, effective risk communication strategies could be necessary to improve the

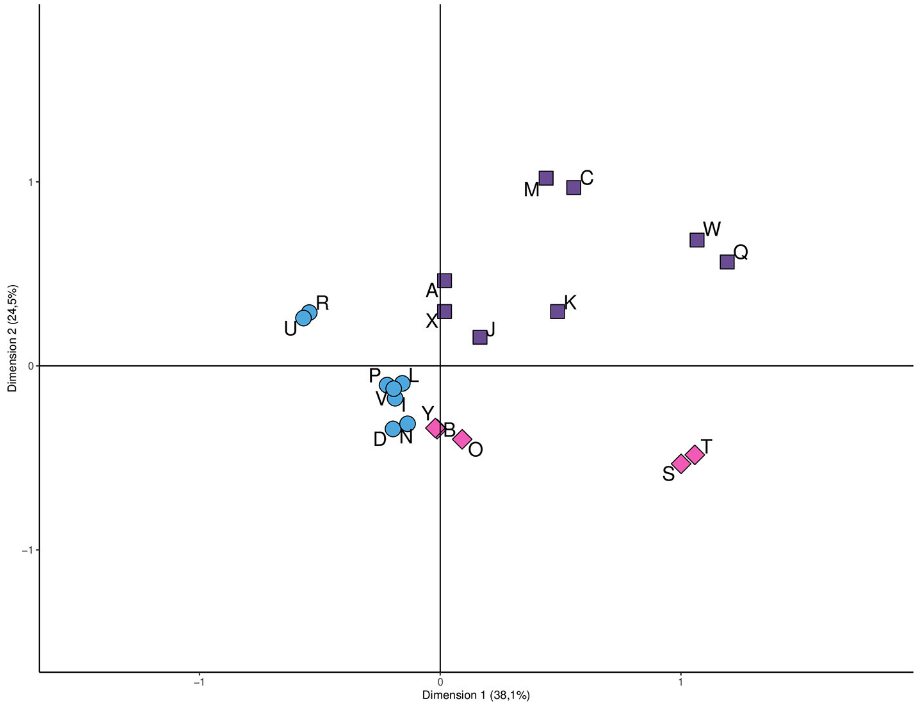

FIGURE 1 | Clustering of variables associated with the potential exposure of hunters to avian influenza viruses. Symbols with the same shape or color belong to the same cluster and their particular characteristics appear below in correspondence with the letter that identifies them. **Cluster 1:** Clean birds at home (D), High hunter experience (I), Have knowledge on avian influenza (L), Direct contact water (N), Clean knives after slaughtering (P), Don't smokes (R), Flu unvaccinated (U), Washing hands after hunt (V); **Cluster 2:** Don't hunt with dog (A); Don't clean birds at home (C), Low hunter experience (J), haven't knowledge on avian influenza (K), Haven't direct contact water (M), Don't clean knives after slaughter (Q), Don't washing hands after hunt (W), Sharing hunting knives in household activities (X); **Cluster 3:** Hunt with Dog (B), Receives bird cleaning assistance (O), Smokes (S), Flu vaccinated (T), Don't share hunt knives in other activities (Y).

knowledge level and generate protective attitudes and practices to reduce exposure risk to AIVs.

The low flu vaccination coverage in the surveyed hunters, may be due to less concern about infection, which is the strongest predictor of vaccination uptake (34) and it constitutes a demand for actions to reduce the risk of reassortment of IAVs in this population stratum. Vaccination is the main measure for preventing seasonal influenza and its potential complications (35). Vaccination of groups with a higher risk of exposure to AIVs, such as poultry workers, is recommended by the anti-pandemic Global Action Plan (36). In Cuba since 1998, the National Vaccination Policy for Seasonal Influenza prioritizes at risk groups (37, 38).

The lack of vaccination in people at higher risk of being exposed to AIVs implies a greater risk of co-infection with different strains, which may lead to reassortment events with potentially harmful consequences. Cross-species transmission of AIVs directly from wild birds to humans is rare, but given the increased risk of exposure to AIV infection in hunters (9), it is clear that they should be prioritized for the seasonal flu vaccination. Evidences of AIV infection in persons with occupational exposure to migratory birds (39) and human coinfection with different AIVs, have been reported (40).

The flu season in American tropics mainly occurs from April to September (41) while long term studies in Cuba, show human influenza virus circulation increases during the rainy season (May-October) (42), which partially overlap with the waterbird migration season during the fall (43). These facts exacerbate the risk of coinfection with IAVs, that are increased in some species of hunted-waterbird with a high prevalence of AIVs like *Spatula discors* (4).

Flu vaccination strengths immunity against human influenza viruses at a population level by reducing the likelihood of coinfection hence decreasing the possibility of generating new progeny viruses by genetic reassortment (44). However, given flu vaccination does not prevent infections by AIVs, other preventive measures must be put in place to complement the reduction of the risk of human infections with AIVs, some of which may cause severe consequences (45).

Wild animal slaughtering, whether done by hunters or their family members, can place both at risk of transmission through direct exposure to blood and internal organs as well as feces (8). Hence, being helped by another family member during bird cleaning, additionally increased the risk of exposing more people. On the other hand, since other family members may be not considered at risk, they may lack protective measures like flu vaccination, and be more prone to IAV coinfection events.

The practice of slaughtering wild birds at home may also increase food safety risks because some pathogens and infectious agents are usually found in meats (46). In particular, the delay

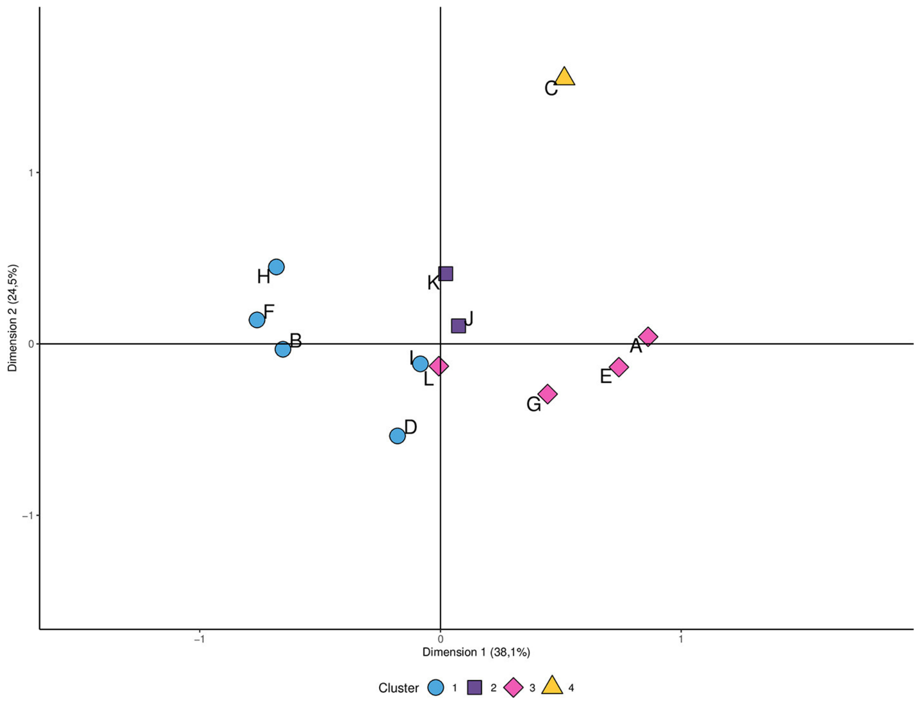

FIGURE 2 | Clustering of variables associated with the potential exposure of domestic animal to avian influenza viruses. Symbols with the same shape or color belong to the same cluster and their particular characteristics appear below in correspondence with the letter that identifies them. **Cluster 1:** Hunt with dog (B); Clean birds at home (D), Having backyard poultry at home (F), Feed domestic animal with bird leftover (H), High hunter experience (I); **Cluster 2:** Low hunter experience (J), Haven't knowledge on avian influenza (K); **Cluster 3:** Don't hunt with dog (A), Haven't backyard poultry at home (E), Don't feed domestic animal with bird leftover (G); Have knowledge on avian influenza (L); **Cluster 4:** Don't clean birds at home (C).

in bird processing after hunting may increase infection risks e.g., through the transfer of enterobacteria from gut to muscles resulting in food borne transmission. Since AIV infections can occur through direct contact with tissues, secretions and excretions of infected birds (9) it is necessary to reduce or eradicate the practice of cleaning hunted birds at home, as well as the use of hunting knives for other household activities.

Smoking prevalence among the surveyed hunters was similar to that of the general population in the country (47). However, smoking in addition to important health implications (48), when practiced in wildlife areas, may increase the threat of fires, with negative impact on the environment and biodiversity.

HPAI is a disease of poultry that evolves from milder viral strains naturally occurring within wild bird populations (13). Hence the hunters that raise poultry and practice birds cleaning at home, could favor low pathogenic AIVs evolve to HPAI (49). Backyard poultry have played different roles in AI epidemics across affected countries (50, 51). Nonetheless, is desirable to prevent backyard poultry exposure to AIVs. Despite the low epidemic potential of AIV infection in backyard poultry, for many families in developing countries, poultry are more than a source of income or food but also play social and cultural roles. Hence backyard poultry must be preserved.

The feeding of domestic animals with birds' leftover could lead to an increase in the host range of the virus and even the disease, as well as the emergence of new subtypes due to the phenomenon of genetic reassortment. It has been shown that antigenic and genetic evolution of IAVs often results in inter-species transmission as the virus adapts to a new host (52). In fact, reports of influenza virus affecting dogs (53, 54) are relatively recent, but they have been important in causing epidemic outbreaks mainly in greyhounds (55). On the other hand, pigs are susceptible to IAVs of avian and human origin (56, 57), which may cause the emergence of new virus. In fact, the H1N1 pandemic virus in 2009 resulted from a novel reassortant among avian, human and swine origin viruses (58, 59).

In the current study, the use of dogs for hunting did not prevent contact of hunters with water. The persistence of AIVs in water and their fecal-oral transmission among waterbirds are of recognized importance in the maintenance of the virus in the ecosystem (60). Therefore, water contact for hunters may result in their exposure to AIVs. Conversely, there are not records of AIV infection in humans acquired through water, despite this material and sediments in wetlands being an important source of such viruses (49).

Direct contact with water during hunting should be a practice to avoid because in addition to the threat of AIVs some other severe disease-causing pathogens like leptospira may be present in wetlands. Interestingly the recruited hunters for the present study indicated higher levels of vaccination coverage for leptospirosis compared to seasonal flu (results no showed).

Higher levels of hunter confidence due to more years of experience could reduce risk perception due to usual practices that apparently do not affect their health, as observed in other studies (10). The risk of infection by AIVs demands the development of communication strategies that improve knowledge through dissemination of public health messages that may cause a change in behavior among hunters. A sound knowledge of the potential risk factors that facilitate the introduction and spread of AIVs in animal and human populations is key to developing preventive control strategies and contributing to active surveillance programs.

No taking into consideration the variables with the inferior limit of OR<1, only smoking and having backyard birds at home remained as significant according to Cerda (61). In particular, smoking habit encompass a well-known health risk itself (48), but it seems not enough to withdraw such practice. On the other hand, having backyard poultry at home it is not a risk, if that are not exposed to AIVs through practices like cleaning hunted birds at home which had OR < 1 even at the superior limit of CI 95%.

Study Strengths and Limitations

Our study aimed to gain an understanding of the bird harvesting practices and attitudes regarding AI exposure among Cuban hunters and to identify gaps in influenza pandemic plans. This research provides information on the population strata (hunters) that have more influence on the risk of infection and dissemination of AIVs. It complements the anti-pandemic plan in the face of the possibility of infections with this pathogen in humans, bearing in mind the necessity of contact between animals and people as a prerequisite for this to occur (8). In addition, it contributes to the strategy's improvement for managing the risk of introduction and dissemination of the AIVs in Cuba. Poultry production in Cuba is an important component of livestock economy with over 35.35 million heads (including hens, ducks, turkeys, quails, among others) with their own breeders (62). The main production from the commercial poultry sector are eggs with a consumption average over 200 per capita egg/year, hence it is an important component of food security.

The location of hunter groups in geographically different areas did not allow for random sampling because a representative group of people is hard to be matched in time and space. Almost 1% of the registered hunters in Cuba were recruited for the study, although active hunting could vary with the availability of cartridges and transportation to hunting sites.

Conclusions

Cuban hunters participate in some practices while harvesting wild birds that could potentially expose them and their domestic animals to AIVs. There was no relation between protective measures reported by hunters and their awareness on avian influenza, which may imply a lack of knowledge on AIV. This study emphasizes the need to introduce more effective risk communication strategies about the consequences of AIVs infecting humans or other animals and emphasizes the importance of reducing risks and exposure.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Research Ethical Committee of the National Center for Animal and Plant Health (CENSA). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

PA, LM, and MA: conceptualization and design of the study. BD-H, FP, DM, and JA: data collection. BD-H, PA, LM, and YA: data processing, analyses, and interpretation. MA and MP: formal analysis. BD-H, PA, and LM: writing—original draft preparation. PA, LM, and MP: writing—review and editing. All authors have read and agreed to the published version of the manuscript.

FUNDING

This study was funded by the project 9483 of the National Program of Agricultural Health. The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

ACKNOWLEDGMENTS

The authors would like to thank the Cuban Federation of Sportive hunting and Rodolfo Castro, that contributed to recruit hunters for this study and the hunters participating for their invaluable contributions. We are also grateful to Christopher Oura and Joseph Giambrone for English language editing.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2021.644786/full#supplementary-material

REFERENCES

1. Short KR, Richard M, Verhagen JH, van Riel D, Schrauwen EJA, van den Brand JMA, et al. One Health, multiple challenges: the inter-species transmission of influenza A virus. *One Heal.* (2015) 1:1–13. doi: 10.1016/j.onehlt.2015.03.001
2. Kim EH, Kim Y, II, Kim SM, Yu KM, Casel MAB, Jang SG, et al. Pathogenic assessment of avian influenza viruses in migratory birds. *Emerg Microbes Infect*. (2021) 10:565–77. doi: 10.1080/22221751.2021.1899769

3. Parys A, Vandoorn E, King J, Graaf A, Pohlmann A, Beer M, et al. Human infection with Eurasian avian-like swine influenza A (H1N1) virus, the Netherlands, September 2019. *Emerg Infect Dis*. (2021) 27:939–43. doi: 10.3201/eid2703.201863
4. Diskin ER, Friedman K, Krauss S, Nolting JM, Poulson RL, Slemons RD, et al. Subtype diversity of influenza A virus in North American waterfowl: a multidecade study. *J Virol*. (2020) 94:e02022:1-15. doi: 10.1128/JVI.02022-19
5. Ganti K, Bagga A, DaSilva J, Shepard SS, Barnes JR, Shriner S, et al. Avian influenza A viruses reassort and diversify differently in mallards and mammals. *Viruses*. (2021) 13:1–17. doi: 10.3390/v13030509
6. Ferro PJ, Budke CM, Peterson MJ, Cox D, Roltsch E, Merendino T, et al. Multiyear surveillance for avian influenza virus in waterfowl from wintering grounds, Texas Coast, USA. *Emerg Infect Dis*. (2010) 16:1224–30. doi: 10.3201/eid1608.091864
7. Li X, Xu B, Shaman J. Pathobiological features favouring the intercontinental dissemination of highly pathogenic avian influenza virus. *R Soc Open Sci*. (2019) 6:190276. doi: 10.1098/rsos.190276
8. Woldehanna S, Zimicki S. An expanded One Health model : integrating social science and One Health to inform study of the human-animal interface. *Soc Sci Med*. (2015) 129:87–95. doi: 10.1016/j.socscimed.2014.10.059
9. Dórea FC, Cole DJ, Stallknecht DE. Quantitative exposure assessment of waterfowl hunters to avian influenza viruses. *Epidemiol Infect*. (2013) 141:1039–49. doi: 10.1017/S0950268812001720
10. Neupane D, Khanal V, Ghimire K, Aro AR, Leppin A. Knowledge, attitudes and practices related to avian influenza among poultry workers in Nepal: a cross sectional study. *BMC Infect Dis*. (2012) 12:76. doi: 10.1186/1471-2334-12-76
11. Ferreri LM, Ortiz L, Geiger G, Barriga GP, Poulson R, Gonzalez-Reiche AS, et al. Improved detection of influenza A virus from blue-winged teals by sequencing directly from swab material. *Ecol Evol*. (2019) 9:6534–46. doi: 10.1002/ece3.5232
12. Jennelle CS, Carstensen M, Hildebrand EC, Wolf PC, Grear DA, Ip HS, et al. Surveillance for highly pathogenic avian influenza in wild turkeys (*Meleagris gallopavo*) of Minnesota, USA during 2015 outbreaks in domestic poultry. *J Wildl Dis*. (2017) 53:616–20. doi: 10.7589/2016-09-205
13. Karo-Karo D, Bodewes R, Wibawa H, Artika IM, Pribadi ES, Diyantoro D, et al. Reassortments among avian influenza A(H5N1) viruses circulating in Indonesia, 2015-2016. *Emerg Infect Dis*. (2019) 25:465–72. doi: 10.3201/eid2503.180167
14. Sinclair JR. Importance of a One Health approach in advancing global health security and the sustainable development goals. *Rev Sci Tech l'OIE*. (2019) 38:145–54. doi: 10.20506/rst.38.1.2949
15. Van Nhu H, Tuyet-Hanh TT, Van NTA, Linh TNQ, Tien TQ. Knowledge, attitudes, and practices of the vietnamese as key factors in controlling COVID-19. *J Community Health*. (2020) 45:1263–9. doi: 10.1007/s10900-020-0 0919-4
16. Al Ahdab S. A cross-sectional survey of knowledge, attitude and practice (KAP) towards COVID-19 pandemic among the Syrian residents. *BMC Public Health*. (2021) 21:296. doi: 10.1186/s12889-021-10353-3
17. Dishman H, Stallknecht D, Cole D. Duck hunters' perceptions of risk for avian influenza, Georgia, USA. *Emerg Infect Dis*. (2010) 16:1279–81. doi: 10.3201/eid1608.100032
18. Charania NA, Martin ID, Liberda EN, Meldrum R, Tsuji LJ. Bird harvesting practices and knowledge, risk perceptions, and attitudes regarding avian influenza among Canadian First Nations subsistence hunters: implications for influenza pandemic plans. *BMC Public Health*. (2014) 14:1113. doi: 10.1186/1471-2458-14-1113
19. Oruganti P, Garabed RB, Moritz M. Hunters' knowledge, attitudes, and practices towards wildlife diseases in Ohio. *Hum Dimens Wildl*. (2018) 23:329–40. doi: 10.1080/10871209.2018.1435839
20. Martínez Cuesta AL. La caza deportiva en Cuba en el camino hacia su sostenibilidad Sport hunting in Cuba on the road to sustainability. *Rev Cienc y Tecnol En La Cult Fis*. (2019) 14:129–32. Available on line at: https://dialnet.unirioja.es/descarga/articulo/6915520.pdf
21. Abramson JH. WINPEPI updated: computer programs for epidemiologists, and their teaching potential. *Epidemiol Perspect Innov*. (2011) 24:241–2. doi: 10.1186/1742-5573-8-1
22. Yoannia Castillo D, Miranda I. COMPAPROP: Sistema para comparación de proporciones múltiples. *Rev Protección Veg*. (2014) 29:231–4. Available on line at: http://scielo.sld.cu/pdf/rpv/v29n3/rpv13314.pdf
23. Lê S, Josse J, Husson F. FactoMineR: an R package for multivariate analysis. *J Stat Softw*. (2008) 25:1–18. doi: 10.18637/jss.v025.i01
24. Bejaei M, Cli MA, Singh A. Multiple correspondence and hierarchical cluster analyses for the profiling of fresh apple customers using data from two marketplaces. *Foods*. (2020) 9:873. doi: 10.3390/foods9070873
25. Hervier B, Devilliers H, Stanciu R, Meyer A, Uzunhan Y, Masseau A, et al. Hierarchical cluster and survival analyses of antisynthetase syndrome: phenotype and outcome are correlated with anti-tRNA synthetase antibody specificity. *Autoimmun Rev*. (2012) 12:210–7. doi: 10.1016/j.autrev.2012.06.006
26. Costa PS, Santos NC, Cunha P, Cotter J, Sousa N. The use of multiple correspondence analysis to explore associations between categories of qualitative variables in healthy ageing. *J Aging Res*. (2013) 2013:1–12. doi: 10.1155/2013/302163
27. Moritz M, Ewing D, Garabed R. On not knowing zoonotic diseases: pastoralists' ethnoveterinary knowledge in the Far North Region of Cameroon. *Hum Organ*. (2013) 72:1–11. doi: 10.17730/humo.72.1.72672642576gw247
28. Kurscheid J, Millar J, Abdurrahman M, Ambarawati IGAA, Suadnya W, Yusuf RP, et al. Knowledge and perceptions of highly pathogenic avian influenza (HPAI) among poultry traders in live bird markets in Bali and Lombok, Indonesia. *PLoS ONE*. (2015) 10:e0139917. doi: 10.1371/journal.pone.0139917
29. Kawahara T, Akiba I, Sakou M, Sakaguchi T, Taniguchi H. Inactivation of human and avian influenza viruses by potassium oleate of natural soap component through exothermic interaction. *PLoS ONE*. (2018) 13:e0204908. doi: 10.1371/journal.pone.0204908
30. Ramey AM, Reeves AB, Drexler JZ, Ackerman JT, De La Cruz S, Lang AS, et al. Influenza A viruses remain infectious for more than seven months in northern wetlands of North America. *Proc R Soc B Biol Sci*. (2020) 287:20201680. doi: 10.1098/rspb.2020.1680
31. Jang Y, Lee J, So B, Lee K, Yun S, Lee M, et al. Evaluation of changes induced by temperature, contact time, and surface in the efficacies of disinfectants against avian influenza virus. *Poult Sci*. (2014) 93:70-6. doi: 10.3382/ps.2013-03452
32. Chan EY, Cheng CK, Tam G, Huang Z, Lee P. Knowledge, attitudes, and practices of Hong Kong population towards human A/H7N9 influenza pandemic preparedness, China, 2014 infectious disease epidemiology. *BMC Public Health*. (2015) 15:943. doi: 10.1186/s12889-015-2245-9
33. Bish A, Michie S. Demographic and attitudinal determinants of protective behaviours during a pandemic: a review. *Br J Health Psychol*. (2010) 15:797–824. doi: 10.1348/135910710X485826
34. Li T, Feng J, Qing P, Fan X, Liu W, Li MX, et al. Attitudes, practices and information needs regarding novel influenza A (H7N9) among employees of food production and operation in Guangzhou, Southern China: a cross-sectional study. *BMC Infect Dis*. (2014) 14:4. doi: 10.1186/1471-2334-14-4
35. Grohskopf LA, Alyanak E, Broder KR, Blanton LH, Fry AM, Jernigan DB, et al. Prevention and control of seasonal influenza with vaccines: recommendations of the advisory committee on immunization practices - United States, 2020 - 21 influenza season. *MMWR Recomm Reports*. (2020) 69:1–24. doi: 10.15585/mmwr.rr6908a1
36. World Health Organization. Summary analysis of 2014 survey of National Influenza Centres in the WHO Global Influenza Surveillance and Response System. *Wkly Epidemiol Rec*. (2014) 89:369–76. Available on line at: https://apps.who.int/iris/handle/10665/242254
37. Ropero-Álvarez AM, El Omeiri N, Kurtis HJ, Danovaro-Holliday MC, Ruiz-Matus C. Influenza vaccination in the Americas: progress and challenges after the 2009 A(H1N1) influenza pandemic. *Hum Vaccin Immunother*. (2016) 12:2206–14. doi: 10.1080/21645515.2016.1157240
38. Hirve S, Lambach P, Paget J, Vandemaele K, Fitzner J, Zhang W. Seasonal influenza vaccine policy, use and effectiveness in the tropics and subtropics - a systematic literature review. *Influenza Other Respi Viruses*. (2016) 10:254–67. doi: 10.1111/irv.12374
39. Shafir SC, Fuller T, Smith TB, Rimoin AW. A national study of individuals who handle migratory birds for evidence of avian and swine-origin influenza virus infections. *J Clin Virol*. (2012) 54:364–7. doi: 10.1016/j.jcv.2012.05.001

40. Zhu Y, Qi X, Cui L, Zhou M, Wang H. Human co-infection with novel avian influenza A H7N9 and influenza A H3N2 viruses in Jiangsu province, China. *Lancet*. (2013) 381:2134. doi: 10.1016/S0140-6736(13)61135-6
41. Durand LO, Cheng P-Y, Palekar R, Clara W, Jara J, Cerpa M, et al. Timing of influenza epidemics and vaccines in the American tropics, 2002-2008, 2011-2014. *Influenza Other Respi Viruses*. (2016) 10:170–5. doi: 10.1111/irv.12371
42. Vega Y, Paulo L, Acosta B, Valdes O, Borroto S, Arencibia A, et al. Influenza's response to climatic variability in the tropical climate: case study cuba. *Virol Mycol*. (2018) 07:2161-0517. doi: 10.4172/2161-0517.1000179
43. Mugica L, Acosta M, Aguilar S, Noel M, Alina H. *Programa de aves acuáticas y marinas. Estado actual de la biodiversidad marino-costera en la región de los archipiélagos del sur de Cuba*. Santo Domingo: Impresos Dominic (2014). p. 101–18.
44. Li X, Liu B, Ma S, Cui P, Liu W, Li Y, et al. High frequency of reassortment after co-infection of chickens with the H4N6 and H9N2 influenza A viruses and the biological characteristics of the reassortants. *Vet Microbiol*. (2018) 222:11–7. doi: 10.1016/j.vetmic.2018.06.011
45. Bui C, Rahman B, Heywood EA, MacIntyre RC. A meta-analysis of the prevalence of influenza A H5N1 and H7N9 infection in birds. *Transbound Emerg Dis*. (2017) 64:967–77. doi: 10.1111/tbed.12466
46. Adesokan HK, Funso-Adu K, Okunlade OA. Foodborne pathogens on meat stored in major central cold rooms in ibadan and their susceptibility to antimicrobial agents. *Folia Vet*. (2020) 64:1–10. doi: 10.2478/fv-2020-0011
47. Lamas RP, Lorenzo TD, Rivera LR. *III Encuesta nacional de factores de riesgo y actividades preventivas de enfermedades no trasmisibles*. Cuba 2010-2011. Havana: Editorial Ciencias Médicas (2014).
48. Wainwright K, Perrotte JK, Bibriescas N, Baumann MR, Garza RT. Smoking expectancies and health perceptions: an analysis of Hispanic subgroups. *Addict Behav*. (2019) 98:106008. doi: 10.1016/j.addbeh.2019.05.032
49. Densmore CL, Iwanowicz DD, Ottinger CA, Hindman LJ, Bessler AM, Iwanowicz LR, et al. Molecular detection of avian influenza virus from sediment samples in waterfowl habitats on the Delmarva Peninsula, United States. *Avian Dis*. (2017) 61:520–5. doi: 10.1637/11687-060917-ResNote.1
50. Smith G, Dunipace S. How backyard poultry flocks influence the effort required to curtail avian influenza epidemics in commercial poultry flocks. *Epidemics*. (2011) 3:71–5. doi: 10.1016/j.epidem.2011.01.003
51. Souvestre M, Guinat C, Niqueux E, Robertet L, Croville G, Paul M, et al. Role of backyard flocks in transmission dynamics of highly pathogenic avian influenza a(H5N8) clade 2.3.4.4, France, 2016-2017. *Emerg Infect Dis*. (2019) 25:551–4. doi: 10.3201/eid2503.181040
52. Chastagner A, Bonin E, Fablet C, Quéguiner S, Hirchaud E, Lucas P, et al. Virus persistence in pig herds led to successive reassortment events between swine and human influenza A viruses , resulting in the emergence of a novel triple reassortant swine influenza virus. *Vet Res*. (2019) 50:1–9. doi: 10.1186/s13567-019-0699-y
53. Jirjis FF, Deshpande MS, Tubbs AL, Jayappa H, Lakshmanan N, Wasmoen TL. Transmission of canine influenza virus (H3N8) among susceptible dogs. *Vet Microbiol*. (2010) 144:303–9. doi: 10.1016/j.vetmic.2010.02.029
54. Liu Y, Fu C, Ye S, Liang Y, Qi Z, Yao C, et al. Phosphoproteomics to characterize host response during H3N2 canine influenza virus infection of dog lung. *Front Vet Sci*. (2020) 7:585071. doi: 10.3389/fvets.2020.585071
55. Parrish CR, Murcia PR, Holmes EC. Influenza virus reservoirs and intermediate hosts: dogs, horses, and new possibilities for influenza virus exposure of humans. *J Virol*. (2015) 89:2990–4. doi: 10.1128/JVI.03146-14
56. Webster RG, Bean WJ, Gorman OT, Chambers TM, Kawaoka Y. Evolution and ecology of influenza A viruses. *Microbiol Rev*. (1992) 56:152–79. doi: 10.1128/mr.56.1.152-179.1992
57. Bourret V. Avian influenza viruses in pigs: an overview. *Vet J*. (2018) 239:7–14. doi: 10.1016/j.tvjl.2018.07.005
58. Neumann G, Kawaoka Y. Transmission of influenza A viruses. *Virology*. (2015) 479–480:234–46. doi: 10.1016/j.virol.2015.03.009
59. He P, Wang G, Mo Y, Yu Q, Xiao X, Yang W, et al. Novel triple-reassortant influenza viruses in pigs, Guangxi, China. *Emerg Microbes Infect*. (2018) 7:1–9. doi: 10.1038/s41426-018-0088-z
60. Numberger D, Dreier C, Vullioud C, Gabriel G, Greenwood AD, Grossart H-P. Recovery of influenza A viruses from lake water and sediments by experimental inoculation. *PLoS ONE*. (2019) 14:e0216880. doi: 10.1371/journal.pone.0216880
61. Cerda J, Vera C, Rada G. Odds ratio: aspectos teóricos y prácticos. *Rev Med Chil*. (2013) 141:1329–35. doi: 10.4067/S0034-98872013001000014
62. ONEI. *Anuario Estadístico de Cuba Enero-Diciembre*. (2019). Cap 9. Agricultura, Ganadería, Silvicultura y Pesca. Edición 2020 n.d.:6–37. Available online at: http://www.onei.gob.cu/node/15006 (accessed December 21, 2020).

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Public Health

COMMUNITY CASE STUDY
published: 02 August 2021
doi: 10.3389/fpubh.2021.652079

Critical Evaluation of Cross-Sectoral Collaborations to Inform the Implementation of the "One Health" Approach in Guadeloupe

Gaëlle Gruel[1†], Mame Boucar Diouf[2,3,4†], Catherine Abadie[5‡], Yolande Chilin-Charles[5,6‡], Eric Marcel Charles Etter[7,8‡], Mariana Geffroy[7,8‡], Cécile Herrmann Storck[9‡], Damien F. Meyer[7,8‡], Nonito Pagès[7,8‡], Gersende Pressat[3,4‡], Pierre-Yves Teycheney[3,4‡], Marie Umber[2‡], Anubis Vega-Rúa[10‡] and Jennifer Pradel[7,8]*

[1] Laboratory for the Study of Microbial Ecosystem Interactions, Institut Pasteur of Guadeloupe, Unit Transmission Reservoir and Pathogens Diversity, Les Abymes, France, [2] INRAE, UR ASTRO, F-97170, Petit-Bourg, France, [3] CIRAD, UMR AGAP Institut, F-97130, Capesterre Belle-Eau, France, [4] AGAP Institut, Univ Montpellier, CIRAD, INRAE, Institut Agro, Montpellier, France, [5] BGPI, Univ Montpellier, CIRAD, INRAE, Institut Agro, Montpellier, France, [6] CIRAD, UMR BGPI, F-97130, Capesterre Belle-Eau, France, [7] CIRAD, UMR ASTRE, F-97170, Petit-Bourg, France, [8] ASTRE, Univ Montpellier, CIRAD INRAE, Montpellier, France, [9] Centre Hospitalier Universitaire CHU de Guadeloupe, Laboratoire de Microbiologie Humaine et Environnementale, Les Abymes, France, [10] Laboratory of Vector Control Research, Institut Pasteur of Guadeloupe, Unit Transmission Reservoir and Pathogens Diversity, Les Abymes, France

OPEN ACCESS

Edited by:
*Laura H. Kahn,
Princeton University, United States*

Reviewed by:
*Séverine Thys,
University of Antwerp, Belgium
Timothy Bouley,
BioFeyn, France*

***Correspondence:**
*Jennifer Pradel
jennifer.pradel@cirad.fr*

† These authors share first authorship

‡ These authors have contributed equally to this work

Specialty section:
This article was submitted to Planetary Health, a section of the journal Frontiers in Public Health

***Received:** 11 January 2021*
***Accepted:** 02 July 2021*
***Published:** 02 August 2021*

Citation:
Gruel G, Diouf MB, Abadie C, Chilin-Charles Y, Etter EMC, Geffroy M, Herrmann Storck C, Meyer DF, Pagès N, Pressat G, Teycheney P-Y, Umber M, Vega-Rúa A and Pradel J (2021) Critical Evaluation of Cross-Sectoral Collaborations to Inform the Implementation of the "One Health" Approach in Guadeloupe. Front. Public Health 9:652079. doi: 10.3389/fpubh.2021.652079

In Guadeloupe, a French overseas territory located in the Eastern Caribbean, infectious and non-infectious diseases, loss of biodiversity, natural disasters and global change threaten the health and well-being of animals, plants, and people. Implementing the "One Health" (OH) approach is crucial to reduce the archipelago's vulnerability to these health threats. However, OH remains underdeveloped in Guadeloupe, hampering efficient and effective intersectoral and transdisciplinary collaborations for disease surveillance and control. A multidisciplinary research group of volunteer researchers working in Guadeloupe, with collective expertise in infectious diseases, undertook a study to identify key attributes for OH operationalization by reviewing past and current local collaborative health initiatives and analyzing how much they mobilized the OH framework. The research group developed and applied an operational OH framework to assess critically collaborative initiatives addressing local health issues. Based on a literature review, a set of 13 opinion-based key criteria was defined. The criteria and associated scoring were measured through semi-directed interviews guided by a questionnaire to critically evaluate four initiatives in animal, human, plant, and environmental health research and epidemiological surveillance. Gaps, levers, and prospects were identified that will help health communities in Guadeloupe envision how to implement the OH approach to better address local health challenges. The methodology is simple, generic, and pragmatic and relies on existing resources. It can be transposed and adapted to other contexts to improve effectiveness and efficiency of OH initiatives, based on lessons-learned of local past or current multi-interdisciplinary and intersectoral initiatives.

Keywords: One Health, evaluation, animal health, human health, plant health, environmental health, operationalization, interdisciplinary and cross-sectoral collaborations

INTRODUCTION

Infectious Diseases Emergence and Wicked Health Problems

It is estimated that 60% of human emerging infectious diseases (EIDs) are zoonotic, of which more than 70–75% originate from wildlife (1, 2). This is exemplified by the emergence over the last 15 years of coronaviruses originating from animals, and more particularly of the SARS-CoV-2 virus causing the current COVID-19 pandemic (3–6). Global change, agricultural intensification, biodiversity loss, climate change, and wildlife trade are known to increase the frequency and incidence of EIDs. Emergence phenomena tend to increase over time (2, 7, 8), and ecosystem degradation is expected to intensify over the next decades (9), affecting local zoonotic host communities and creating hazardous interfaces between people, livestock, and wild reservoirs of zoonotic diseases resulting in increased pandemics risks (10). A panel of experts of the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) estimates that 631,000–827,000 of the 1.7 million undiscovered viruses existing in animals could have the ability to infect humans (11). Environmental pollutants are also known to promote metabolic disorders such as obesity, cardiovascular diseases, diabetes, cognitive development impairments, and cancers (12–14). The emergence and global spread of plant pathogens are also promoted by global change and trade, threatening food security, and human health (15, 16).

In this context, recommendations to implement multidisciplinary and cross-sectoral approaches to tackle complex health problems are increasing (11, 17–20), prompting efforts to address health issues at a global scale through "One Health" (OH) approaches in human, animal, and environmental sectors (7, 19, 21, 22). These approaches have the potential to improve the resilience of socio-ecosystems and reduce health disaster risks. Therefore, they are well-suited to vulnerable territories confronted by natural disasters, climate change, and health risks brought by international trade flows, such as Guadeloupe and other Caribbean islands (23).

Problematic

The OH concept is defined as a collaborative, multisectoral, and transdisciplinary approach working at the local, regional, national, and global levels to achieve optimal health outcomes and recognizes the interconnection between people, animals, plants, and their shared environment (24). There is a consensus in the literature about the benefits of OH approaches such as improvements in human and animal health, well-being, and animal welfare, more effective and rapid disease control or biosecurity measures, improved information and data sharing, environmental protection for healthier ecosystems, enhanced social, and cultural values, more efficient disease surveillance networks (25). However, clear recommendations to successfully implement those approaches are critically needed (26–28).

Rationale

OH remains underdeveloped and poorly promoted in Guadeloupe, impeding efficient and effective cross-sectoral and transdisciplinary collaborations to address the surveillance and control of zoonotic and plant diseases, or new emerging threats. In order to tackle those threats, new forms of collaboration involving multidisciplinary stakeholder groups from health and public/private sectors are needed. In this paper, a multidisciplinary research group reports on identifying key attributes for operational OH initiatives and their use to assess local animal, public, plant, and environmental health collaborative initiatives. The method is generic and can be adapted to other contexts to inform the implementation of an operational and impactful OH approach.

CONTEXT

Guadeloupe

Guadeloupe is a French overseas department located in the Lesser Antilles (Eastern Caribbean). Despite its modest size (1,628 km^2), Guadeloupe archipelago concentrates a great diversity of land and marine ecosystems, making it one of the 34 world's biodiversity hotspots (9, 29). Guadeloupe is prone to natural disasters [hurricanes, earthquakes, volcanic eruptions, tsunamis (30)] and threatened by anthropogenic and climate change: habitat destruction, long-lasting water and soil contamination by persistent organic pollutants like pesticides (31–33), sea-level rise and increased frequency and intensity of extreme weather events (34). This results in emerging environmental health issues such as coral reef decline (35), Sahara sand dust (36), and harmful macroalgal blooms outbreaks causing massive strandings (37).

Guadeloupe has strong connections through tourism and trade with neighboring Caribbean countries and territories, North America, and Europe. This results in large flows of people, animals, plants, and by-products that threaten global health and local biodiversity, and agricultural productivity through the potential introduction of exotic pests and diseases. Thus, over the last two decades, Guadeloupe has experienced several emerging infectious disease outbreaks in humans or animals (West Nile virus, Chikungunya, Zika, dengue, leptospirosis, COVID-19) (38, 39), and crops (Black Leaf Streak Disease of banana, Huanglongbing of citrus, anthracnose of yam, coconut lethal yellowing...) (40–44). Additional exotic emerging infectious diseases, such as banana fusarium wilt tropical race 4 (45) or African swine fever (46, 47) are currently spreading worldwide at a worrying speed, hence threatening Guadeloupe's agriculture, economy, and food security.

To address these challenges, the effective OH implementation based on achievements of current/past programmes is crucial to commensurate with the challenges faced by the archipelago.

Abbreviations: ARS, Regional Health Agency; BLSD, Black Leaf Streak Disease; CHUG, University Hospital Center of Guadeloupe; CIRAD, French Agricultural Research Centre for International Development; DAAF, Food, Agriculture, and Forest Direction of the ministry of agriculture; ECOHI, Evaluation Criteria for OH Implementation; EID, Emerging Infectious Diseases; ERDF, European Research and Development Funds; INRAe, National Research Institute for Agriculture, Food and Environment; IPG, Institut Pasteur of Guadeloupe; MALIN, Maladies infectieuses en milieu insulaire tropical—infectious diseases in tropical island environments; NEOH, Network of EcoHealth and OH; SPF, Public Health France; WNV, West Nile Virus; UA, University of Antilles.

Collaborative Research and Surveillance Programs in Guadeloupe

Guadeloupe has built strong local research communities and surveillance networks to characterize, prevent and control priority infectious diseases in humans, animals, and plants. This was done through a 6-year collaborative project, "Malin" (2014–2020) (48). The response to local health challenges relies on world-class scientific infrastructures, including reference, and high-level biosafety laboratories, with dedicated human resources. Public research organizations, hospitals, and agencies involved in human, animal, and plant health, surveillance, and innovation transfer engaged in interdisciplinary approaches and rationalization of resources via several collaborative initiatives. Four of them were assessed in this study:

- West Nile Virus (WNV) surveillance network. WNV is a mosquito-borne flavivirus that affects humans, equines, and birds. In 2002, seroconversions in horses and poultry provided the first indirect evidence of WNV circulation in Guadeloupe (49). Since then, epidemiological surveillance programs were enforced by several organizations involved in animal or public health to monitor WNV in horses, birds, mosquitoes, and humans and to improve knowledge on WNV epidemiology in Guadeloupe. However, the surveillance remains primarily sectoral with limited communication between its veterinary and public health components. After operating for more than 15 years, the network is currently shifting towards an integrated surveillance system with a pilot implementation of the OH approach (50).
- Black Leaf Streak Disease (BLSD) surveillance network. BLSD is a foliar disease of banana. It is caused by an ascomycete fungus causing major production losses (up to 100%) and reduced fruit greenlife, threatening the banana industry worldwide (51). The BLSD surveillance network was implemented in 2009 in Guadeloupe to prevent BLSD introduction. However, BLSD was first detected in Guadeloupe in 2012, prompting the network to promote a collaborative action plan including long-term disease management strategies targeting citizens and professionals from the banana industry. This plan included monthly biological surveillance based on the observation of sentinel banana plots spread over the entire territory. The network has since extended its activities to early detection and control of other banana emerging diseases.
- KaruBioNet is a collaborative interdisciplinary bioinformatics and biostatistics network. It was created in 2019 and involves scientists, engineers, and students. It aims to foster multidisciplinary collaborations and to provide mutual support for improving human, plant, and animal health in Guadeloupe through the implementation of bioinformatics. KaruBioNet members assist each other with the analysis, integration, and interpretation of bioinformatics data through shared access of the joint high-performance computing center of the University of Antilles (UA) (52).
- INSULA is a collaborative research project funded jointly by the European Commission and the Guadeloupe regional council. The project started in 2020 and aims to assess the influence of the ecosystem's biodiversity and its human-induced modifications on the diversity of vector-borne viruses affecting plants, animals, and humans in Guadeloupe, using the OH approach (53). It was implemented to bridge a collaboration gap between environmental health and ecology, building on a previous local collaboration between botanists and epidemiologists to unravel the eco-epidemiology of WNV in Guadeloupe (50, 54).

DETAILS TO UNDERSTAND KEY PROGRAMMATIC ELEMENTS

The development of an operational framework to assess how much local health initiatives have mobilized the OH approach has been conducted to identify major gaps, levers, and perspectives to enhance OH collaborations.

Methods

Eighteen volunteer scientists referred to as "OH leaders" (OHLs) were involved in an 18-month capacity-building program on OH leadership. This program started in November 2019 and was facilitated by international experts: Profs. Craig Stephen (Canadian Wildlife Health Cooperation) and Christopher Oura (University of the West Indies). This OHL group includes researchers, engineers, Ph.D. students, laboratory technicians, medical/hospital, and epidemiological surveillance practitioners working in Guadeloupe in research/surveillance organizations. Their expertise encompass human, animal, and plant microbiology, medical entomology, animal and plant epidemiology, plant virology, and human infectious diseases. Volunteers joined this group following a call of interest launched within the Malin consortium. Motivation and commitment to follow the program were the only requirements for joining. The OHL group worked on this study between October and November 2020 as a part of the OH leadership program.

The OHL group searched for key attributes of successful OH operations. For this, members undertook a literature review of recent (<6 years) peer-reviewed publications on OH evaluation (55) published by OH reference groups like the Network of EcoHealth and OH (NEOH) (56) and organizations advocating for the implementation of OH internationally (57). They used PubMed and Web of Science, with One Health*, assessment*, implementation*, operational*, practice*, success*, recommendation* and benefits* as keywords. The OHL group shared publications using MoodleCloud™ and Mendeley™. Group members then reviewed, discussed, prioritized, and defined sets of criteria and their scores, corresponding to what the group judged critical for the successful implementation of OH initiatives, also using their own experiences. Consensual definitions for each Evaluation Criterion for OH Implementation (ECOHI) and their scoring rules were developed.

The OHL group developed a questionnaire to inform ECOHI scores using semi-directed group interviews (**Supplementary Material**). The questionnaire was first piloted on another collaborative health program (not assessed) conducted in Guadeloupe to evaluate its feasibility, then revised and reorganized to ease its utilization. Four local initiatives were selected for assessment based on the following criteria: they ought to be collaborative, multi/interdisciplinary and cross-sectoral, deal with animal, human, plant and/or environmental health, and ongoing (**Table 1**).

The questionnaire was used as a guide to assess the initiatives through interviews of groups of two to four persons most knowledgeable about each assessed initiative. Interviews intended to seek group perceptions and shared experiences between partners. Before interviews, each interviewee was informed about the goal and the course of the study. Interviewees accepted freely to participate, agreed that the interview was recorded and that the information shared would be anonymized and used for publication. All signed a formal letter of consent.

The four 2-h interviews were carried out between 19th and 25th November 2020 via ZOOM™. Interviewers were two OHLs familiar with the methodology but not with the assessed initiative. To minimize possible biases, an epidemiologist attended all interviews as an observer. The interviewers scored initiatives immediately after each interview. Scores were converted into percentages relative to the maximum ECOHI, and represented on a radar diagram using Excel software (Microsoft, Redmond, USA). During a final working session, the OHL group reviewed the results, harmonized their interpretation of the answers, and adjusted scores accordingly to minimize person-dependent variations. The individual criterion scores were averaged to compute the score of the initiative. A group brainstorming ensued to analyze and interpret the results in terms of gaps and successes and detailed recommendations to improve OH implementation.

A total of eight 3-h working sessions were organized by the OHL group, both face-to-face and virtually, using Microsoft TEAMS™.

Results

A set of 13 opinion-based ECOHIs was developed and categorized in three types: "Governance"; "Partnership"; and "Resources" (**Table 2**), with scores ranging from 1 (minimum) to 2 to 4 (maximum) (**Table 3**).

A total of 52 scores were obtained (**Table 4**). **Figure 1** shows how assessed initiatives performed for each criterion according to their scores. The average score computed over the 13 ECOHI expresses the degree to which key OH attributes are applied. The variation of the scores may reflect differences in the nature and objectives of the initiative.

Overall, most initiatives performed well on some key attributes associated with interdisciplinary and cross-sectoral collaboration in health: "pooling of resources," "collaborative dimension," and "diversity of stakeholders involved" with some noticeable strength on "governance" and "recognition of the OH professionals' role." On the contrary, they are weaker on "soft skills of OH workers," "integrated data analysis," and the "OH awareness of non-scientific/technical stakeholders" (**Table 4**).

The WNV surveillance network displayed the lowest overall score compared to the other initiatives, especially for ECOHIs of categories 1 ("collaborative planning" and "adaptive coordination and monitoring") and 3 ("supporting

TABLE 1 | Short description of the health collaborative initiatives assessed in Guadeloupe.

Name	Nature	Health sector involved	Objective	Partners (disciplines and organization)	Other stakeholders involved	OH focused?
WNV surveillance	Epidemiological surveillance network	Animal and human health	Monitor West Nile disease in sentinel animals and humans, improve WNV knowledge.	Medical practitioners, epidemiologists, hospital researchers (CHUG, CIRAD), public health practitioners (ARS, SPF), and agriculture organizations (DAAF), private veterinarians.	Horse center, poultry farmers	No
BLSD Surveillance	Epidemiological surveillance network	Plant Health	Prevent, monitor and control Black Leaf Streak Disease.	Scientists (CIRAD), government officers from the French plant protection services (DAAF), a technical organization specialized in plant health surveillance (FREDON), technical tropical crops Institute (IT2) and banana producers (LPG).	Family Garden	No
KaruBioNet	Expertise Network	Disciplinary network	Improve collaboration and structuration of bioinformatics in Guadeloupe.	Researchers, post-graduate students working in biology, computer science, health informatics, biostatistics, mathematics mainly. Partners: CIRAD, IPG, INSERM, INRAe, UA, CIC, Resource Biologic Center (KaruBioTec).	NA	No
INSULA	Research project	Animal, plant, human and environmental health	Assess the biodiversity of ecosystems and the influence of human-induced modifications on vector-borne viruses of plants, animals and humans risks.	Researchers in ecology, epidemiology, virology, entomology, botany, metagenomics from 4 research institutes in Guadeloupe (CIRAD, IPG, INRAe, UA) and Belgium (KU Leuven) as well as 2 NGOs involved in bird and bat conservation.	NGOs, government, regional, and international agencies involved in conservation, professional, citizen organizations, municipalities.	Yes

TABLE 2 | Selected criteria considered key attributes for the successful implementation of OH initiatives (ECOHI), definitions, and associated scoring.

Category	#	Criterion	Definition	References
1. Governance	1	Holistic thinking	The health problem is analyzed as a whole, using a systemic approach, considering the complex interactions between the processes and actors involved/concerned by health issues. The initiative has been thought of in a holistic, integrative, and non-specific way. It considers multiple disciplines, sectors (health and public/private), species, and integration at different spatial scales. It aims to integrate the knowledge of the various stakeholders, from the analysis of the problem to its resolution.	(58–60)
	2	Governance	New forms of governance to sustain relationships and long-term collaborations are defined (processes, rules) to ensure equitable distribution of decision-making power and resources. In addition, clear and transparent rules for operating principles and overall management exist.	(19, 28, 60–62)
	3	Collaborative planning	Planning requires that aims, problem formulation, responsibilities, and financing are clear, organized, and shared regardless of paradigms, organizational hierarchies, sectors, and stakeholders' disciplines. It needs resources (competencies, time, tools) to involve all key stakeholders in the planning; and clarity in establishing tasks and responsibilities.	(28, 59, 62)
	4	Adaptive coordination and monitoring	Due to the complex and cross-domain characteristics of OH collaboration, the initiative is deftly coordinated. It is characterized by adaptive planning and flexible implementation in the face of changes (new knowledge, the emergence of constraints or opportunities), making the initiative a part of a continuous improvement process. This dynamic monitoring of the initiative is characterized by the ability to continuously self-evaluate, learn, and adapt.	(27, 28, 59, 62, 63)
2. Partnership	5	Collaborative dimension and knowledge integration	The collaborative initiative involves stakeholders with different skills, working in public or private organizations (research, academia, producers, sales, public institutions, etc.) and health (animal, plant, environmental, and human) sectors in all phases (thinking, implementation, analysis, feedback). Participatory methods or a framework (multi-criteria analysis, system thinking, and transdisciplinary approach) are in place to engage stakeholders and integrate their knowledge (multi-criteria analysis, systemic analysis, transdisciplinary approaches, and other methodological guidelines).	(19, 27, 60, 63–66)
	6	Stakeholders diversity	A variety of stakeholders are involved in the initiative, including academic and non-academic groups, some of them traditionally linked to the health field (beneficiaries, ministries, international organizations, practitioners, technical institutes, industry) or not (private or public sector, other sectors of the civil society). They participate actively in the initiative, and they are effectively and ideally involved in all stages of the initiative.	(18, 26, 27, 63, 65)
	7	OH professionals' role recognition	One Health professionals have the freedom and ability to get involved in collaborative initiatives (by sharing their time, knowledge, skills, and other support). Their role is recognized and supported by their institutions/hierarchies and they can engage in horizontal programmes*. Mobility between sectors and organizations facilitates the development of "One Health" human resources. The recognition and support they receive marks an awareness of the "One Health" approach by their hierarchies and an understanding of its benefits. *Horizontal programs are organized across institutions, teams, or services.	(65)
	8	OH awareness of non-scientific stakeholders	Non-technical and non-scientific stakeholders (donors, civil society, governmental/NGO organizations, and associations) are sensitized to the OH approach and take ownership of it, facilitating their participation in the initiative. This can result from active awareness campaigns (public debates, participatory workshops, training sessions, etc.) or other means of communication (press releases, website, social media, radio, T.V., etc.) organized by the initiative or by the stakeholders themselves.	(19, 27, 65)
	9	Soft skills of OH professionals	OH professionals of the initiative are trained on soft skills [participatory sciences, management (horizontal leadership), and communication (intercultural communication, conflict management)] to lead, operationalize and sustain OH programs. The technical skills needed to work in multidisciplinary settings, experience in group processes, and team development foster inter-professional communication, collaboration, and help build relationships and trust.	(28, 57, 61, 64, 67)
3. Resources	10	Supporting infrastructure	Supporting infrastructure (management tools, databases, human resources) is available to ease fund transfer between agencies and organizations to facilitate the implementation of OH programs. This enables monitoring and follow-up of multiple, strongly connected, and coordinated activities. It allows to more easily share (knowledge/information/resources, staff), learn from the initiative (knowledge exchange, institutional memory, feedback, self-regulation): and adopt a systemic organization (polycentric organization, high connectivity, synchronization, and multidimensions).	(28, 57, 61, 62, 64)

(Continued)

TABLE 2 | Continued

Category	#	Criterion	Definition	References
	11	Synergistic pooling of resources	Pooling of resources (human, financial, technical platforms, knowledge) beneficial to all parties is in place, enabling progress to be made on the initiative's critical points, organizing synergies, and optimizing these resources.	(19)
	12	Data and information sharing	Appropriate procedures for sharing and accessing data/information exist and are implemented. There are appropriate infrastructure and resources for managing heterogeneous data regarding quality, quantity, and nature. The willingness of stakeholders to share data and information is vital.	(18, 27, 28)
	13	Integrated data analysis	Data is collected following protocols defined and validated by the stakeholders. A data management plan has been put in place, facilitating the cleaning and validation of the data and its integrated analysis. This integrated analysis makes it possible to answer a common question and improve all partners' knowledge. All data from different partners is used in integrated data analysis.	(27, 64)

ECOHIs were grouped into 3 categories: category 1, governance; category 2, partnership; category 3, resources.

infrastructure," "pooling of resources," "data/information sharing," and "integrated data analysis") (**Table 4** and **Supplementary Material**). Some flaws in network governance (set of bodies and rules for decision-making, management, and operating principles to ensure strategic directions and oversight) negatively impact other ECOHIs such as "Integrated data analysis," "data sharing," or "synergistic pooling of resources." Indeed, collaboration between the human and veterinary sectors in charge of equine, avian, and entomological surveillance remain low, despite WNV being an ideal OH disease model and the network being built using an integrative approach involving stakeholders from various disciplines in the animal and public health sectors willing to collaborate.

In contrast, the BLSD surveillance network had the second-highest average score and the best scores on several ECOHIs (**Table 4** and **Supplementary Material**). The network has good governance and resource mobilization strategy (all resources available in surveillance partners were used for BLSD surveillance in a complementary way, with shared advantages/benefits for all parties) with rules ensuring equitable distribution of decision-making power and resources. This resulted in a high degree of collaboration between partners that translates into the high scores on "data/information sharing" (all partners received regular feedbacks) and "adaptive coordination and dynamic monitoring" (the network was highly flexible to adjust to changes in the disease situation). On the contrary, the network fared poorly for three ECOHIs: (i) "soft skills" (trust, team building, conflict management), that could help stakeholders to work better together if more complex problems arise in the future; (ii) "integrated data analysis" (only one partner in charge of data analysis); and (iii) "OH awareness" (OH is a new concept for most plant specialists). Finally, "supporting infrastructure" (management tools, databases, human resources) got a medium score: partners wished they could have more useful tools to save time for technical tasks.

The INSULA project had the highest average score (**Table 4** and **Supplementary Material**). It is the only initiative that was conceived and implemented using a OH approach. Hence four critical ECOHIs of categories 1 and 2 reached maximum scores for "holistic thinking," "new forms of governance," "stakeholders' diversity," and the "collaborative dimension and knowledge integration." This scoring reflects the strong willingness of the project's partners (i) to implement an interdisciplinary approach; (ii) to involve ecologists and the environmental health sector in a health project; (iii) to focus on a cross-cutting topic, namely vector-borne viral diseases; and (iv) to share resources. Project partners have developed a common database and other collaborative tools for easier data/information sharing and integrated data analysis. Two ECOHIs could not be evaluated because no data had been produced yet at the time of interviews.

Despite being a relatively new network, KaruBioNet showed several assets (**Table 4** and **Supplementary Material**). Its governance ensures equitable distribution of decision-making and resources; the pooling of resources and supporting infrastructure, including a shared super calculator made freely available for the local research community; sharing information, and data, which is the raison d'être of the network. The network was not initially conceived as a OH initiative; hence it fared poorly on several ECOHIs: "holistic thinking," "adaptive coordination and monitoring," and "stakeholders' diversity." "OH awareness of non-scientific stakeholders" and "soft skills of OH professionals" were both not applicable. Interestingly, KaruBioNet does not conduct integrated data analysis as the information and data shared are not intended to be analyzed jointly. However, this network may do so in the future depending on its active involvement in collaborative projects and therefore become a key player in implementing the OH concept in Guadeloupe.

DISCUSSION

Lessons-Learned From Current Collaborations

Challenges in implementing interdisciplinary and cross-sectoral programs occur at all stages throughout their lifespan (27). Interestingly, the framework developed in our study was applied to initiatives of different natures (research project, technical or disease surveillance networks) at different development stages—with WNV surveillance being the oldest (18 years old) and INSULA the most recent (5 months). The joint analysis of

TABLE 3 | Definition of the scores for each Evaluation Criteria for OH Implementation (ECOHI).

ECOHI	Scoring levels	Scores' definitions
1. Holistic thinking	3	1: Specific (sectoral/disciplinary) approach and analysis of the health problem were used. 2: A broader approach has been used to be more integrative of stakeholders (disciplines and sectors), however, there was no systemic analysis. 3: A holistic approach and a systemic analysis of the health problem were used.
2. Governance	2	1: There is no proper governance and rules and processes if they exist (decision making, operating principles, management) are not adapted. 2: There is good collaborative governance and coordination/information sharing mechanism aligned with rules and procedures.
3. Collaborative planning	3	1: Overall planning is organized according to sectors and organizational hierarchy. There is a lack of shared roles, responsibilities, and resources. There are no resources (competencies, time) to facilitate the initiative across sectors and disciplines. 2: Overall planning is organized regardless of sectors and organizations. Roles, responsibilities, and resources are shared however there are no/few resources to facilitate the initiative across sectors and disciplines. 3: Overall planning is organized regardless of sectors and organizations. Roles, responsibilities, and resources are shared and there are resources to facilitate the initiative across disciplines and sectors.
4. Adaptive coordination and monitoring	3	1: There is an annual monitoring process and basic coordination in place. 2: There are regular follow-up meetings with an analysis of difficulties/opportunities; however, no recommendations nor corrective/preventive actions are formulated/implemented. 3: There is dynamic monitoring and adaptive coordination of the initiative allowing evolving as changes occur. Recommendations or preventive and/or corrective actions are implemented.
5. Collaborative dimension and knowledge integration	4	1: The initiative is not collaborative: it is disciplinary and sectoral. 2: The collaborations are multidisciplinary but not multisectoral; there is no knowledge integration. 3: The collaborations are interdisciplinary and multisectoral, however, there is poor/some knowledge integration (no specific methods used). 4: The collaborations are inter/transdisciplinary and multisectoral, and stakeholders' partners knowledge is integrated using participatory or dedicated frameworks/methodologies.
6. Stakeholders' diversity	3	1: Stakeholders relevant to the initiative have not all been identified and do not participate in the initiative. 2: Stakeholders involved are only those traditionally associated with the health sector. They participate in all or part of the initiative. 3: Stakeholders including those associated with other sectors than health and relevant to the initiative have been identified and actively participate in all phases.
7. OH professionals' role recognition	3	1: The role of OH professionals is not recognized within their institution(s) and/or by the hierarchy. 2: The role of OH professionals is recognized, but they cannot invest time, share skills/knowledge, or provide any other support type in horizontal programs. 3: The role of OH professionals is recognized, allowing them to invest themselves in horizontal programs by sharing skills, knowledge, invest time, and provide any other type of support.
8. OH awareness of non-scientific stakeholders	3	1: Non-technical/scientific stakeholders are poorly informed/not aware of the OH approach used in the initiative. 2: Non-technical/scientific stakeholders are aware of the OH approach however they don't participate in the initiative. 3: Non-technical/scientific stakeholders take ownership of the OH approach and participate in the initiative.
9. Soft skills of OH professionals	3	1: No team building/trust development strategy is in place (awareness/training of stakeholders in humanities and behavioral sciences; organization of social events...). 2: A team-building/trust development strategy is in place (trained/awareness of stakeholders in humanities and behavioral sciences, social events organized as part of the initiative,...). 3: A team-building/trust development strategy is in place and is implemented to develop the social networking.
10. Supporting infrastructure	2	1: There is no supporting infrastructure other than the classical means of projects that are not multidisciplinary/sectoral. 2: Supporting infrastructure has been put into place and facilitates sharing, learning, and systemic organization.
11. Synergistic pooling of resources	3	1: No resource is available/allocated to the OH initiative; if resources are available, they are not pooled. 2: The available resources of the stakeholders are pooled for the OH initiative, but the benefits are limited to a couple of stakeholders. 3: Stakeholders' resources are pooled for the OH initiative and results in shared advantages/benefits with all parties.
12. Data/Information Sharing	3	1: No mechanism for sharing and managing data and information has been put in place and/or there is no willingness of data/information sharing. 2: There are procedures for data and information sharing and management, however, the access is restricted to a limited number of people or is not easy. 3: There is an active exchange of data and information between stakeholders following the procedures established within the initiative's framework.
13. Integrated data analysis	3	1: No definition of data collection protocol or data management plan. 2: A data collection protocol and/or data management plan has been developed, but the data analysis is not integrated. 3: A data collection and management are carried out as defined by the protocols and plans, the data analysis is integrated.

TABLE 4 | Scores obtained for each criterion and each initiative, with a total score also expressed in relative percentage (in bracket).

	ECOHI	WNV surveillance	BLSD surveillance	INSULA project	KaruBioNet	Score max	Average
1	Holistic thinking	2 (67%)	2 (67%)	3 (100%)	1.5 (50%)	3	2.1 (71%)
2	Governance	1 (50%)	2 (100%)	2 (100%)	2 (100%)	2	1.7 (88%)
3	Collaborative planning	1 (33%)	2.5 (83%)	2 (67%)	2.5 (83%)	3	2 (67%)
4	Adaptive coordination and monitoring	1 (33%)	3 (100%)	2 (67%)	1.5 (50%)	3	1.9 (63%)
5	Collaborative dimension and integration of knowledge	3 (75%)	3 (75%)	4 (100%)	3 (75%)	4	3.2 (81%)
6	Diversity of the stakeholders involved	2 (67%)	2 (67%)	3 (100%)	1.5 (50%)	3	2.1 (71%)
7	OH professionals' role recognition	1.5 (50%)	2.5 (83%)	3 (100%)	2.5 (83%)	3	2.3 (79%)
8	OH awareness of non-scientific stakeholders	1 (33%)	1 (33%)	1 (33%)	1 (33%)	3	1 (33%)
9	Soft skills of OH professionals	2 (67%)	1 (33%)	2 (67%)	1 (33%)	3	1.5 (50%)
10	Supporting infrastructure	1 (50%)	1 (50%)	1.5 (75%)	1.5 (75%)	2	1.2 (63%)
11	Synergistic pooling of resources	1 (33%)	3 (100%)	3 (100%)	2.5 (83%)	3	2.4 (79%)
12	Data/Information sharing	1 (33%)	2.5 (83%)	1.5 (50%)	3 (100%)	3	2 (67%)
13	Integrated data analysis	1 (33%)	2 (67%)	1.5 (50%)	1 (33%)	3	1.38 (46%)
	Average program score (%)	18.5 (48%)	27.5 (72%)	29.5 (78%)	24.5 (65%)	38	25 (66%)

Average scores were calculated for ECOHI and for each initiative.

those initiatives, which share the same local context, provides relevant insights to inform future and ongoing collaborative OH initiatives in Guadeloupe. The OHL group also gained experience working on this joint study.

Study Highlights

Learning by Doing

The preliminary agreement on the meaning and definitions of ECOHI and scores greatly facilitated communication between the OHLs and with interviewees. Moreover, as previously experienced by similar groups (28, 68), the OHLs had to maximize organizational flexibility to overcome collaborative challenges. The teamwork's methodology and action plan were therefore revised at each group meeting to incorporate new insights and knowledge while balancing effective progress with members' commitment. This resulted in a more comprehensive program even though it took twice longer than planned.

All interviewees were positive about the study and acknowledged that it helped them change their perspective on OH. The semi-directed interviews allowed them to share experiences, to examine collectively past challenges and successes, and to reflect on recommendations for improving their own work. The method was simple, easily implemented, and delivered results quickly. The study also raised awareness on OH, of which most interviewees had only partial knowledge. Cross-sectoral communication benefited tremendously: e.g., it allowed animal health experts to exchange views on surveillance practices with plant health experts, and the OHLs were made aware of the initiatives evaluated throughout the evaluation process, which will help design future collaborative projects involving all health sectors.

Although three out of four initiatives were not initially OH in scope, they performed well on several key attributes associated with interdisciplinary and cross-sectoral collaboration. This encouraging result demonstrates that there is a local culture of collaboration. This could be explained by the small size of the territory, which favors the proximity of the different stakeholders of the scientific health community, exchanges and communication, making collaborations easier compared to larger territories.

Contrasting Results Between a Plant and a Zoonotic Disease Surveillance Network

Although WNV is a good model for developing OH approaches and despite a strong willingness of its members to collaborate, the WNV surveillance network scored low as the animal and human health sectors do not work together closely enough. On the contrary, the banana health surveillance network proved successful in delivering practical outcomes such as an efficient collaborative surveillance system based on early detection and an emergency response plan similar to what was successfully implemented in Australia (69).

The outcome of two decades of WNV sectorial work in Guadeloupe proved disappointing. The virus itself has not been isolated, its impact on human and animal populations is still unknown, and its local epidemiological cycle remains poorly understood. This situation could result from the epidemiology of WNV being complex in the Neotropics and very different from what is observed in North America (70, 71), and from the limited resources allocated to WNV in Guadeloupe. Since early 2020, WNV surveillance actors have been involved in a OH pilot project and agreed to create an integrated surveillance network aiming to operate more efficiently and effectively (50).

The BLSD initiative relies primarily on collaborations across disciplines and sectors (research, government agencies, technical institute, growers associations). This resulted in efficient management of the disease upon its outbreak in Guadeloupe and prevented panic in the population. The three network partners interviewed acknowledged that the high economic impact of BLSD helped achieve these outcomes because disease control was a top and shared priority for all stakeholders. This is a marked

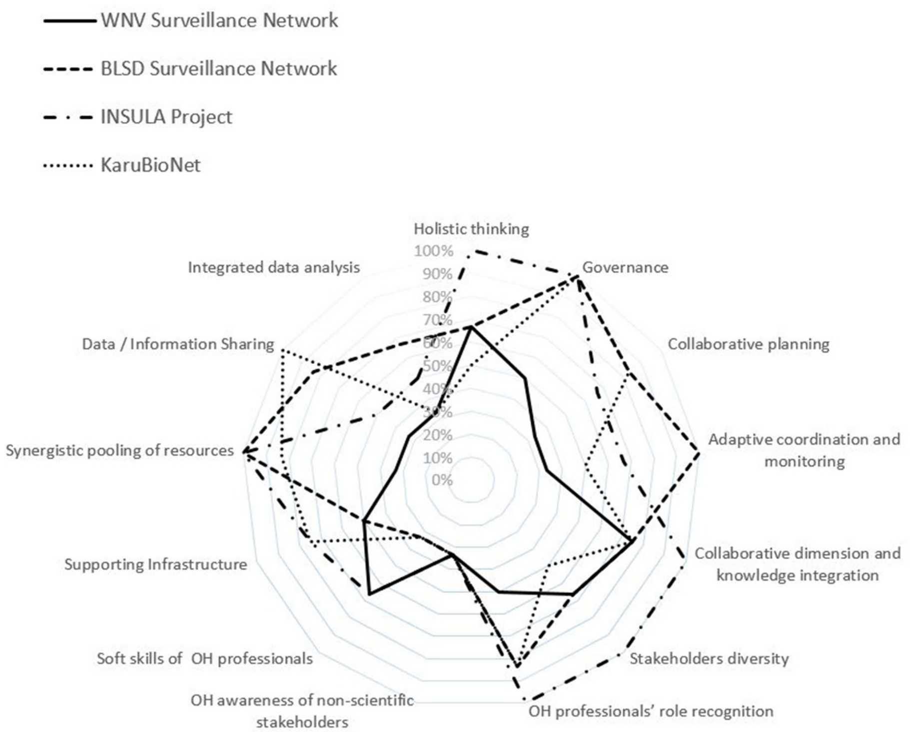

FIGURE 1 | Radar diagrams displaying the scores (in %) for each ECOHI criterion for all the initiatives (**Supplementary Figures 1A–D**).

difference with the WNV network, as WNV is not a priority for the public health sector (50).

Continuous Improvement in the Implementation of the OH Concept in Guadeloupe

The INSULA project's maximum scores for several ECOHI ("holistic thinking," "governance," "collaborative dimension," and "diversity of the stakeholders") reflects progress in implementing OH in Guadeloupe. Indeed, the project benefits from previous experiences, such as the WNV and BLSD networks, through the direct participation of researchers involved in those networks. This helped avoid the pitfalls that have hampered earlier initiatives to various extent. In addition, the project was conceived and planned by a multidisciplinary group willing to collaborate with the environmental sector and tackle major environmental and health issues in Guadeloupe. Project participants agreed to share human resources, equipment, and infrastructures, demonstrating their willingness to move one step forward towards implementing the One Health approach in Guadeloupe. This has proved instrumental in securing funding from a competitive call for projects.

Gaps and Weaknesses

Overall, the evaluation conducted herein revealed that all assessed initiatives fare poorly on three ECOHI: 1/ "integrated data analysis"; 2/ "soft skills of OH professionals"; and 3/ "OH awareness of non-scientific stakeholders" showing that health communities in Guadeloupe still have to work on these aspects to foster the OH approach.

Integrated Data Analysis

"Integrated data analysis" is likely to improve in Guadeloupe if future projects are conceived collaboratively and if proper conditions and environments are created for data/information sharing (27). Although the INSULA project scored low for this criterion, it is likely to deliver a proper and shared integrated data analysis thanks to both project's governance and its design. Indeed, a consortium agreement is being prepared; dedicated secured platforms for data and information sharing are being created; protocols for data collection and management are being drafted. Finally, a dedicated 2-year engineer assistant has been recruited to collect, share, and manage data through a shared database under construction.

However, integrated data analysis can succeed only if challenges related to the implementation, monitoring and evaluation phases are anticipated and overcome (27, 28). These challenges include an ECOHI of extreme importance: "soft skills of OH professionals" for which the four initiatives fared poorly.

Importance of Soft Skills and Social Sciences

"Soft skills of OH professionals" include leadership, horizontal management, participatory sciences, experience in group processes, intercultural communication, conflict management, team development, etc. They are essential to lead, operationalize and sustain OH programs (28, 57, 61, 64, 67, 72), but are often overlooked (61). These skills can be brought by stakeholders and/or OH facilitators. They are instrumental in preventing and solving problems arising from collaborations between actors working in multiple domains, who do not have a collaboration history, or from institutional/academic or geographic and cultural fragmentation (27). Those skills are needed to work in multidisciplinary settings, foster communication, and relationship-building, which are essential in the local context, where the health and research systems are fragmented into small and scattered disciplinary teams. Development of trust and engagement of actors result in well-managed and coordinated collaborative programs with real integration of expertise and knowledge as opposed to artificial collaborations where stakeholders work together but remain in their silo (27); this was somehow experienced during the "Malin" project. If health communities of Guadeloupe aim to steward ambitious and long-lasting OH programs, they will need to define a strategy to fill those gaps in OH soft skills. In particular, collaboration with social scientists is important and efforts are ongoing.

Importance of OH Awareness

The lack of "OH awareness among non-technical and non-scientific stakeholders' groups" (e.g., funder, civil society, governmental/non-governmental organization, etc.) may have had a minor impact on the initiatives that did not have a strong OH scope. On the opposite, it is important to fill this gap with the many stakeholders of the INSULA project while it is getting off the ground, and with the WNV surveillance network that aims to shift towards an integrated network. According to their objectives and long-term goals, OH programs are expected to benefit tremendously from raising OH awareness among groups not traditionally involved in health projects. For instance, the BLSD surveillance network actors stressed out the importance of associating the public to the prevention and control of BLSD. Public awareness and actors' engagement maximize the impact of projects, promote innovations (65), and positively influence funding policies. It also enhances the proximity with scientists, thus contributing to fight the growing distrust of science among the public that prevents society from serenely debating major issues such as GMOs, vaccination or climate change (73).

Importance of Supporting Infrastructures

While supporting infrastructures (management tools, databases, human resources) are available for KaruBioNet and INSULA, they are vitally needed for the surveillance networks assessed. The lack of supporting infrastructures did not prevent the BLSD network from meeting its objectives, but it resulted in an increased workload for the actors, which is unsustainable in the long-term. This lack could prove problematic if another emerging banana disease was introduced and required additional work. In contrast, the lack of supporting infrastructure impacted WNV surveillance markedly, preventing the network from sharing data and information. An Information System coupled with RShiny (RStudio®) for dynamic and interactive data visualization was developed recently to pilot a more integrated network, along with new communication routes (50). More generally, surveillance networks would benefit from project management tools and geographic information systems to monitor the progress of control actions to support health interventions, reduce costs, and save time and energy.

Importance of Holistic Approach

Only one initiative (INSULA) scored maximum on "Holistic thinking," meaning that a holistic approach and a systemic analysis of the health problem were used (**Table 3**), stressing the need for capacity-building in system thinking and system analysis in Guadeloupe, which can be conducted using participatory methods as described by Duboz et al. (58).

Methodological Limitations

We proposed a semi-quantitative method based on the analysis of 13 criteria to assess the OH framework implementation in collaborative initiatives rapidly, whereas some participatory methods were developed to implement OH initiatives, such as disease surveillance, requiring several workshops and more time (74). If our approach delivers on results quickly, an action plan tailored to each initiative should be defined to improve its efficiency and effectiveness.

The design of interviews (different interviewers for each initiative assessed, some OHLs being interviewed) may generate biases. These biases were minimized by implementing corrective actions such as: group interviews, interviewers external to the initiative, same observing epidemiologist participating in all interviews, group analysis of the interviews results. No major difference was noticed in the interpretation of questions among the OHL group. Finally, emphasizing the main objective of the interviews—learning from initiatives rather than comparing their performance—helped keep objectivity. This design facilitated cross-sectoral communication and the exchange of experience.

Several excellent scores were assigned, suggesting an advanced level of key OH attributes implementation in Guadeloupe, although the OH approach remains under-developed in Guadeloupe. This is due to the limited number of scoring levels with maximum values accounting for both promising/good and excellent/outstanding results. Adding an additional scoring level would not have been relevant in our context. NEOH tools should be considered for a more thorough "OH-ness" assessment of more advanced OH programs (59).

Although the INSULA project is just starting, all ECOHIs were scored—those not applicable were scored minimum. In contrast, those relating to the implementation phase ("collaborative planning," "adaptive coordination and monitoring," "data sharing," "integrated data surveillance") were scored according to available information. The low scores reflect the lack of information rather than real issues. In general, it would be worth re-evaluating young initiatives like INSULA once they are more advanced.

Implementing a Change-Oriented Strategy to Enhance OH in Guadeloupe

Identifying problems, gaps, and making recommendations is far easier than identifying implementable solutions leading to meaningful results (27). The work reported in this paper shows that the OH community in Guadeloupe is ready to move one step further towards the building of a strategy based on the theory of change to implement sustainable good OH practices involving diverse stakeholders.

For this, the OHL group will use an approach for building *ex-ante* impact pathways ("ImpresS *ex ante*") based on the approach developed by Blundo Canto et al. (75). This participatory, iterative and adaptive approach is particularly well-suited to OH issues. It consists of a 3 to 4-day face-to-face participatory workshop. A group of relevant stakeholders, including decision makers, builds a shared vision of the future (desired impacts) over a 5 to 10-year period and develops a common strategy, including a plausible and sound implementation plan. Participants agree on desired outcomes regarding change of behavior, practices and capacities. Then, they identify the key challenges preventing those from occurring and propose plausible and realistic solutions that will overcome those challenges. This approach is being increasingly implemented to improve the impact of collaborative projects through easier, more efficient, and more fruitful collaborations. It has also been applied to strengthen stakeholders engagement and cooperation in surveillance systems to better tackle major challenges in public health such as antimicrobial resistance (74).

CONCLUSIONS

The lessons learned from this study and the use of the methodological framework described in this paper are expected to improve not only existing initiatives but also the design and implementation of future ones. For example, the OHL group is currently building a new collaborative project based on a systemic analysis of the health problems they want to address, using the lessons learned from the Malin project, and the outcomes of this study.

The scope of our study can be improved and broadened by including more socio-economic analysis and programs carried out in Guadeloupe by other research groups and involving grass-roots or other stakeholders. The proposed strategy could also be adapted to other Caribbean states and territories, and be helpful for evaluating quickly OH collaborative initiatives around the world before more in-depth analysis.

As described in this paper, implementing OH approaches requires a paradigm shift towards fully effective, strategic and broad-spectrum institutional collaboration to ensure better health for humans, animals, plants, and the environment. This process can be viewed as the "Rosetta stone" that enables cross-sectoral associations to implement technical, organizational, and political solutions to address future health crises. We are confident that the synergy resulting from implementing a OH approach in Guadeloupe will help reshape its health system towards a more holistic health approach.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

JP designed, coordinated, and organized all phases of the project. JP, MG, CA, YC-C, P-YT, MD, MU, and CH conducted the interviews and data collection from partners. GG, MD, and JP drafted the article and supervised the writing of the paper. All authors participated in all steps of the work, contributed to the drafting and the revision of the article, and approved the submitted version.

FUNDING

This work was a part of the MALIN project funded by the European Union and the Guadeloupe Regional Council under the European Research and Development Funds (ERDF) 2014-2020 program (Grant 2018-FED-1084).

ACKNOWLEDGMENTS

Authors are indebted to Prof. Craig Stephen and Prof. Christopher Oura for their support and guidance throughout the OH leadership capacity-building program. The authors wish to thank Christina Jakoby-Koaly (FREDON), Marcus Hery (Institut Technique Tropical), Lydéric Aubert and Jean-Loup Chappert (Santé Publique France), David Couvin and Alexis Dereeper (Institut Pasteur de Guadeloupe), Alain Rousteau (Université des Antilles), and Frédéric Salmon (CIRAD) for participating in the interviews.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2021.652079/full#supplementary-material

REFERENCES

1. Taylor LH, Latham SM, Woolhouse MEJ. Risk factors for human disease emergence. *Philos Trans R Soc B Biol Sci.* (2001) 356:983–9. doi: 10.1098/rstb.2001.0888
2. Jones KE, Patel NG, Levy MA, Storeygard A, Balk D, Gittleman JL, et al. Global trends in emerging infectious diseases. *Nature.* (2008) 451:990–3. doi: 10.1038/nature06536
3. Meurens F, Dunoyer C, Fourichon C, Gerdts V, Haddad N, Kortekaas J, et al. Animal board invited review: risks of zoonotic disease emergence at

the interface of wildlife and livestock systems. *Anim Int J Anim Biosci.* (2021) 15:100241. doi: 10.1016/j.animal.2021.100241

4. Plowright RK, Parrish CR, McCallum H, Hudson PJ, Ko AI, Graham AL, et al. Pathways to zoonotic spillover. *Nat Rev Microbiol.* (2017) 15:502–10. doi: 10.1038/nrmicro.2017.45
5. Bloom JD, Chan YA, Baric RS, Bjorkman PJ, Cobey S, Deverman BE, et al. Investigate the origins of COVID-19. *Science.* (2021) 372:694. doi: 10.1126/science.abj0016
6. Hu B, Guo H, Zhou P, Shi ZL. Characteristics of SARS-CoV-2 and COVID-19. *Nat Rev Microbiol.* (2021) 19:141–54. doi: 10.1038/s41579-020-00459-7
7. Morand S, Walther B. The accelerated infectious disease risk in the Anthropocene: more outbreaks and wider global spread. *bioRXiv [preprint].* (2020). doi: 10.1101/2020.04.20.049866
8. McMahon BJ, Morand S, Gray JS. Ecosystem change and zoonoses in the Anthropocene. *Zoonoses Public Health.* (2018) 65:755–65. doi: 10.1111/zph.12489
9. Brooks TM, Mittermeier RA, Mittermeier CG, Da Fonseca GAB, Rylands AB, Konstant WR, et al. Habitat loss and extinction in the hotspots of biodiversity. *Conserv Biol.* (2002) 16:909–23. doi: 10.1046/j.1523-1739.2002.00530.x
10. Gibb R, Redding DW, Chin KQ, Donnelly CA, Blackburn TM, Newbold T, et al. Zoonotic host diversity increases in human-dominated ecosystems. *Nature.* (2020) 584:398–402. doi: 10.1038/s41586-020-2562-8
11. Daszak P, das Neves C, Amuasi J, Hayman D, Kuiken T, Roche B, et al. *IPBES Workshop on Biodiversity and Pandemics, Executive Summary*. Bonn: IPBES secretariat (2020). p. 1–51. doi: 10.5281/zenodo.4147317
12. Le Magueresse-Battistoni B, Vidal H, Naville D. Environmental pollutants and metabolic disorders: the multi-exposure scenario of life. *Front Endocrinol.* (2018) 9:582. doi: 10.3389/fendo.2018.00582
13. Nedellec V, Rabl A, Dab W. Public health and chronic low chlordecone exposure in Guadeloupe, part 1: hazards, exposure-response functions, and exposures. *Environ Heal A Glob Access Sci Source.* (2016) 15:75. doi: 10.1186/s12940-016-0160-x
14. Nedellec V, Rabl A, Dab W. Public health and chronic low chlordecone exposures in Guadeloupe; part 2: health impacts, and benefits of prevention. *Environ Heal A Glob Access Sci Source.* (2016) 15: 78. doi: 10.1186/s12940-016-0159-3
15. Richardson J, Lockhart C, Pongolini S, Karesh WB, Baylis M, Goldberg T, et al. Drivers for emerging issues in animal and plant health. *EFSA J.* (2016) 14:e00512. doi: 10.2903/j.efsa.2016.s0512
16. Strobl E, Mohan P. Climate and the global spread and impact of Bananas' Black Leaf Sigatoka disease. *Atmosphere.* (2020) 11:1–19. doi: 10.3390/ATMOS11090947
17. Stephen C, Karesh WB. Is One Health delivering results? Introduction. *Rev Sci Tech.* (2014) 33:375–9. doi: 10.20506/rst.33.2.2301
18. World Health Organization. Food and Agriculture Organization of the United Nations. & World Organisation for animal health. *Taking a multisectoral, One Health approach: A Tripartite Guide to Addressing Zoonotic Diseases in Countries*. (2019).
19. Berthe F, Bouley T, Karesh WB, LeGall F, Machalaba C, Planté C, et al. *One Health - Operational Framework for Strengthening Human, Animal and Environmental Public Health Systems at their Interface*. Washington, DC. (2018). Available online at: http://documents.worldbank.org/curated/en/703711517234402168/pdf/123023-REVISED-PUBLIC-World-Bank-One-Health-Framework-2018.pdf (accessed December 15, 2020).
20. Barton Behravesh C. Introduction. One Health: over a decade of progress on the road to sustainability. *Rev Sci Tech.* (2019) 38:21–50. doi: 10.20506/rst.38.1.2939
21. Zell R. Global climate change and the emergence/re-emergence of infectious diseases. *Int J Med Microbiol Suppl.* (2004) 293:16–26. doi: 10.1016/S1433-1128(04)80005-6
22. Ryu S, Kim BI, Lim JS, Tan CS, Chun BC. One health perspectives on emerging public health threats. *J Prev Med Public Heal.* (2017) 50:411–4. doi: 10.3961/jpmph.17.097
23. Simpson M, Scott D, Trotz U. *Climate Change's Impact on the Caribbean's Ability to Sustain Tourism, Natural Assets, and Livelihoods.* Inter-American Dev Bank Environ Safeguards Unit Tech NOTES (2011). p. 14. Available online at: http://www.uncclearn.org/sites/default/files/inventory/idb14.pdf (accessed December 15, 2020).
24. Lerner H, Berg C. A comparison of three holistic approaches to health: One Health, ecohealth, and planetary health. *Front Vet Sci.* (2017) 4:163. doi: 10.3389/fvets.2017.00163
25. Häsler B, Cornelsen L, Bennani H, Rushton J. A review of the metrics for One Health benefits. *OIE Rev Sci Tech.* (2014) 33:453–64. doi: 10.20506/rst.33.2.2294
26. Lebov J, Grieger K, Womack D, Zaccaro D, Whitehead N, Kowalcyk B, et al. A framework for One Health research. *One Heal.* (2017) 3:44–50. doi: 10.1016/j.onehlt.2017.03.004
27. dos S. Ribeiro C, van de Burgwal LHM, Regeer BJ. Overcoming challenges for designing and implementing the One Health approach: a systematic review of the literature. *One Heal.* (2019) 7:100085. doi: 10.1016/j.onehlt.2019.100085
28. Errecaborde KM, Macy KW, Pekol A, Perez S, O'Brien MK, Allen I, et al. Factors that enable effective One Health collaborations - a scoping review of the literature. *PLoS ONE.* (2019) 14:1–24. doi: 10.1371/journal.pone.0224660
29. Maunder M, Leiva A, Santiago-Valentín E, Stevenson DW, Acevedo-Rodríguez P, Meerow AW, et al. Plant conservation in the Caribbean island biodiversity hotspot. *Bot Rev.* (2008) 74:197–207. doi: 10.1007/s12229-008-9007-7
30. Scolobig A, Komendantova N, Patt A, Vinchon C, Monfort-Climent D, Begoubou-Valerius M, et al. Multi-risk governance for natural hazards in Naples and Guadeloupe. *Nat Hazards.* (2014) 73:1523–45. doi: 10.1007/s11069-014-1152-1
31. Crabit A, Cattan P, Colin F, Voltz M. Soil and river contamination patterns of chlordecone in a tropical volcanic catchment in the French West Indies (Guadeloupe). *Environ Pollut.* (2016) 212:615–26. doi: 10.1016/j.envpol.2016.02.055
32. Maudouit M, Rochoy M. Systematic review of the impact of chlordecone on human health in the French West Indies. *Therapie.* (2019) 74:611–25. doi: 10.1016/j.therap.2019.01.010
33. Cabidoche YM, Achard R, Cattan P, Clermont-Dauphin C, Massat F, Sansoulet J. Long-term pollution by chlordecone of tropical volcanic soils in the French West Indies: a simple leaching model accounts for current residue. *Environ Pollut.* (2009) 157:1697–705. doi: 10.1016/j.envpol.2008.12.015
34. Stephenson TS, Vincent LA, Allen T, Van Meerbeeck CJ, Mclean N, Peterson TC, et al. Changes in extreme temperature and precipitation in the Caribbean region, 1961-2010. *Int J Climatol.* (2014) 34:2957–71. doi: 10.1002/joc.3889
35. Cramer KL, Jackson JBC, Donovan MK, Greenstein BJ, Korpanty CA, Cook GM, et al. Widespread loss of Caribbean acroporid corals was underway before coral bleaching and disease outbreaks. *Sci Adv.* (2020) 6:eaax9395. doi: 10.1126/sciadv.aax9395
36. Cadelis G, Tourres R, Molinie J. Short-term effects of the particulate pollutants contained in Saharan dust on the visits of children to the emergency department due to asthmatic conditions in Guadeloupe (French archipelago of the Caribbean). *PLoS ONE.* (2014) 9:e91136. doi: 10.1371/journal.pone.0091136
37. Smetacek V, Zingone A. Green and golden seaweed tides on the rise. *Nature.* (2013) 504:84–8. doi: 10.1038/nature12860
38. Herrmann-Storck C, Saint Louis M, Foucand T, Lamaury I, Deloumeaux J, Baranton G, et al. Severe leptospirosis in hospitalized patients, Guadeloupe. *Emerg Infect Dis.* (2010) 16:331–4. doi: 10.3201/eid1602.090139
39. Vasquez V, Haddad E, Perignon A, Jaureguiberry S, Brichler S, Leparc-Goffart I, et al. Dengue, chikungunya, and Zika virus infections imported to Paris between 2009 and 2016: Characteristics and correlation with outbreaks in the French overseas territories of Guadeloupe and Martinique. *Int J Infect Dis.* (2018) 72:34–9. doi: 10.1016/j.ijid.2018.05.007
40. Cellier G, Moreau A, Cassam N, Hostachy B, Ryckewaert P, Aurela L, et al. First report of 'candidatus liberibacter asiaticus' associated with huanglongbing on citrus latifolia in Martinique and Guadeloupe, French West Indies. *Plant Dis.* (2013) 98:683–3. doi: 10.1094/PDIS-08-13-0879-PDN
41. Loos R, Hubert J, Abadie C, Duféal D, Opdebeeck G, Iotti J. First report of black sigatoka disease in banana caused by *Mycosphaerella fijiensis* on martinique island. *PLant Dis.* (2011) 95:359. doi: 10.1094/PDIS-11-10-0850
42. Penet L, Barthe E, Alleyne A, Blazy JM. Disease risk perception and diversity of management strategies by farmers: the case of anthracnose

caused by Colletotrichum gloeosporioides on water yams (*Dioscorea alata*) in Guadeloupe. *Crop Prot.* (2016) 88:7–17. doi: 10.1016/j.cropro.2016.05.005
43. Gurr GM, Johnson AC, Ash GJ, Wilson BAL, Ero MM, Pilotti CA, et al. Coconut lethal yellowing diseases: a phytoplasma threat to palms of global economic and social significance. *Front Plant Sci.* (2016) 7:1521. doi: 10.3389/fpls.2016.01521
44. DAAFGuadeloupe. *Première détection du phytoplasme responsable du jaunissement mortel du palmier en Guadeloupe*. (2021). Available online at: https://daaf.guadeloupe.agriculture.gouv.fr/Premiere-detection-du-phytoplasme (accessed June 18, 2021).
45. Viljoen A, Ma L-J, Molina AB. Chapter 8: Fusarium wilt (panama disease) monoculture in banana production: resurgence of a century-old disease. In: Ristaino JB, Records A, editors. *Emerging Plant Diseases Global Food Security*. St. Paul, MN: American Phytopathological Society (2020). p. 159–84. doi: 10.1094/9780890546383.008
46. Schulz K, Conraths FJ, Blome S, Staubach C, Sauter-Louis C. African swine fever: fast and furious or slow and steady? *Viruses.* (2019) 11:866. doi: 10.3390/v11090866
47. Gaudreault NN, Madden DW, Wilson WC, Trujillo JD, Richt JA. African swine fever virus: an emerging DNA arbovirus. *Front Vet Sci.* (2020) 7: 59–191. doi: 10.3389/fvets.2020.00215
48. Teycheney P-Y. *Malin Project - Infectious Diseases in Tropical Environment (Guadeloupe).* Available online at: https://www.projet-malin.fr/ (accessed December 15, 2020).
49. Quirin R, Salas M, Zientara S, Zeller H, Labie J, Murri S, et al. West nile virus, Guadeloupe. *Emerg Infect Dis.* (2004) 10:706–8. doi: 10.3201/eid1004.030465
50. Geffroy M, Pages N, Chavernac D, Dereeper A, Aubert L, Herrmann-Storck C, et al. Shifting from sectoral to integrated surveillance by changing collaborative practices: application to west nile virus surveillance in a small Island State of the Caribbean. *Front Public Heal.* (2021) 9:649190. doi: 10.3389/fpubh.2021.649190
51. De Bellaire LDL, Fouré E, Abadie C, Carlier J. Black Leaf Streak disease is challenging the banana industry. *Fruits.* (2010) 65:327–42. doi: 10.1051/fruits/2010034
52. Karubionet. *Network of Bioinformatics and Biostatistics of Guadeloupe*. Available online at: http://www.pasteur-guadeloupe.fr/karubionet.html (accessed December 15, 2020).
53. Teycheney P-Y. *Insula Project*. Available online at: https://www.projet-malin.fr/projet-insula/presentation (accessed December 15, 2020).
54. Pradel J, Chalvet Monfray K, Molia S, Vachiéry N, Rousteau A, Imbert D, et al. Risk factors for West Nile virus seropositivity of equids in Guadeloupe. *Prev Vet Med.* (2009) 92:71–8. doi: 10.1016/j.prevetmed.2009.07.001
55. Grant MJ, Booth A, Centre S. A typology of reviews : an analysis of 14 review types and associated methodologies. *Health Inform Lib J.* (2009) 26:91–108. doi: 10.1111/j.1471-1842.2009.00848.x
56. Häsler B, Jaenisch T. *Network of EcoHealth and One Health*. Available online at: https://neoh.onehealthglobal.net (accessed December 15, 2020).
57. Yamada A, Kahn LH, Kaplan B, Monath TP, Woodall J, Conti L. Chapter 8: One health: from concept to practice. In: Yamada A, Kahn LH, Kaplan B, Monath TP, Lisa Conti JW, editors. *Confronting Emerging Zoonoses: The One Health Paradigm*. Tokyo: Springer (2014). p. 1–254. doi: 10.1007/978-4-431-55120-1
58. Duboz R, Echaubard P, Promburom P, Kilvington M, Ross H, Allen W, et al. Systems thinking in practice: participatory modeling as a foundation for Integrated Approaches to Health. *Front Vet Sci.* (2018) 5:303. doi: 10.3389/fvets.2018.00303
59. Rüegg SR, Nielsen LR, Buttigieg SC, Santa M, Aragrande M, Canali M, et al. A systems approach to evaluate One Health initiatives. *Front Vet Sci.* (2018) 5:23. doi: 10.3389/fvets.2018.00023
60. Hitziger M, Esposito R, Canali M, Aragrande M, Häsler B, Rüegg SR. Knowledge integration in one health policy formulation, implementation and evaluation. *Bull World Health Organ.* (2018) 96:211–8. doi: 10.2471/BLT.17.202705
61. Stephen C, Stemshorn B. Leadership, governance and partnerships are essential One Health competencies. *One Heal.* (2016) 2:161–3. doi: 10.1016/j.onehlt.2016.10.002
62. Rüegg SR, McMahon BJ, Häsler B, Esposito R, Nielsen LR, Speranza CI, et al. A blueprint to evaluate one health. *Front Public Heal.* (2017) 5:20. doi: 10.3389/fpubh.2017.00020
63. Wilcox BA, Aguirre AA, De Paula N, Siriaroonrat B, Echaubard P. Operationalizing one health employing social-ecological systems theory: lessons from the Greater Mekong Sub-region. *Front Public Heal.* (2019) 7:85. doi: 10.3389/fpubh.2019.00085
64. Keune H, Flandroy L, Thys S, De Regge N, Mori M, Antoine-Moussiaux N, et al. The need for European OneHealth/EcoHealth networks. *Arch Public Heal.* (2017) 75:1–8. doi: 10.1186/s13690-017-0232-6
65. Mazet JAK, Uhart MM, Keyyu JD. Stakeholders in One Health. *OIE Rev Sci Tech.* (2014) 33:443–52. doi: 10.20506/rst.33.2.2295
66. Binot A, Duboz R, Promburom P, Phimpraphai W, Cappelle J, Lajaunie C, et al. A framework to promote collective action within the One Health community of practice: using participatory modelling to enable interdisciplinary, cross-sectoral and multi-level integration. *One Heal.* (2015) 1:44–8. doi: 10.1016/j.onehlt.2015.09.001
67. Steele SG, Toribio JA, Booy R, Mor SM. What makes an effective One Health clinical practitioner? Opinions of Australian One Health experts. *One Heal.* (2019) 8:100108. doi: 10.1016/j.onehlt.2019.100108
68. Errecaborde KM, Rist C, Travis D, Ragan V, Potter T. Evaluating One Health : the role of team science in multisectoral collaboration what do we know about. (2019) 38:279–89. doi: 10.20506/rst.38.1.2960
69. Henderson J, Pattemore JA, Porchun SC, Hayden HL, Van Brunschot S, Grice KRE, et al. Black Sigatoka disease: new technologies to strengthen eradication strategies in Australia. *Australas Plant Pathol.* (2006) 35:181–93. doi: 10.1071/AP06017
70. Kramer LD, Ciota AT, Kilpatrick AM. Introduction, spread and establishment of west nile virus in the Americas. *J Med Entomol.* (2019) 1148–55. doi: 10.1093/jme/tjz151
71. Hadfield J, Brito AF, Swetnam DM, Vogels CBF, Tokarz RE, Andersen KG, et al. Twenty years of West Nile virus spread and evolution in the Americas visualized by Nextstrain. *PLoS Pathog.* (2019) 15:e1008042. doi: 10.1371/journal.ppat.1008042
72. Barrera R, MacKay a, Amador M, Vasquez J, Smith J, Díaz a, et al. Mosquito vectors of West Nile virus during an epizootic outbreak in Puerto Rico. *J Med Entomol.* (2010) 47:1185–95. doi: 10.1603/ME10038
73. Kabat GC. Taking distrust of science seriously. *EMBO Rep.* (2017) 18:1052–5. doi: 10.15252/embr.201744294
74. Bordier M, Goutard FL, Antoine-Moussiaux N, Pham-Duc P, Lailler R, Binot A. Engaging stakeholders in the design of One Health surveillance systems: a participatory approach. *Front Vet Sci.* (2021) 8:646458. doi: 10.3389/fvets.2021.646458
75. Blundo Canto G, Faure G, Hainzelin E, Monier C, Triomphe B, Vall E. *ImpresS Ex Ante. An Approach for Building Ex Ante Impact Pathways*. Montpellier (2018). doi: 10.19182/agritrop/00013

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

frontiers in Public Health

REVIEW
published: 14 September 2021
doi: 10.3389/fpubh.2021.687110

From the Approach to the Concept: One Health in Latin America-Experiences and Perspectives in Brazil, Chile, and Colombia

Christina Pettan-Brewer[1,2], Andreza Francisco Martins[3], Daniel Paiva Barros de Abreu[4], Ana Pérola Drulla Brandão[5], David Soeiro Barbosa[6], Daniela P. Figueroa[7], Natalia Cediel[8], Laura H. Kahn[9], Daniel Friguglietti Brandespim[10], Juan Carlos Carrascal Velásquez[11], Adolorata Aparecida Bianco Carvalho[12], Angela Maria Magosso Takayanagui[13], Juliana Arena Galhardo[14], Luiz Flávio Arreguy Maia-Filho[15], Cláudia Turra Pimpão[16], Creuza Rachel Vicente[17] and Alexander Welker Biondo[18,19]*

[1] Department of Comparative Medicine, School of Medicine, University of Washington, Seattle, WA, United States, [2] One Health Brasil, Brazil, Brazil, [3] Applied Microbiology Laboratory, Medical Sciences Department, Federal University of Rio Grande Do Sul (UFRGS), Porto Alegre, Brazil, [4] Laboratory of Molecular Biology, Department of Parasitology, Veterinary Institute, Federal Rural University of Rio de Janeiro (UFRRJ), Seropédica, Brazil, [5] Department of Preventive Medicine, School of Medicine, University of São Paulo, Brazil Ministry of Health, Brasilia, and Portal Saúde Única, São Paulo, Brazil, [6] Department of Parasitology, Institute of Biological Sciences, Federal University of Minas Gerais (UFMG), Belo Horizonte, Brazil, [7] Ecophysiological Modeling laboratory, Liberal Arts Faculty, Adolfo Ibáñez University and Applied Research Center of Chile (CIACHI) of Science and Education Foundation, Santiago, Chile, [8] School of Agricultural Sciences, De La Salle University, Bogota, Colombia, [9] Princeton School of Public Health and International Affairs, Princeton University, New Jersey and One Health Initiative Pro-Bono, Princeton, NJ, United States, [10] Department of Veterinary Medicine, Rural Federal University of Pernambuco, Recife, Brazil, [11] One Health Colombia, Veterinary Medicine and Zootechnics Faculty, University of Cordoba, Montería, Colombia, [12] Department of Pathology, Theriogenology and One Health, School of Agricultural and Veterinarian Sciences, São Paulo State University (Unesp), Jaboticabal, Brazil, [13] Environmental Health Laboratory, Department of Maternal-Infant and Public Health, School of Nursing, University of São Paulo, Ribeirão Preto, Brazil, [14] School of Veterinary Medicine, Federal University of Mato Grosso Do Sul (UFMS), Campo Grande, Brazil, [15] Department of Economics, Rural Federal University of Pernambuco (UFRPE), Recife, Brazil, [16] School of Life Science, Pontifícia Universidade Católica Do Paraná (PUCPR), Curitiba, Brazil, [17] Department of Social Medicine, Federal University of Espírito Santo (UFES), Vitória, Brazil, [18] Department of Veterinary Medicine, Federal University of Parana (UFPR), Curitiba, Brazil, [19] Purdue University, East Lafayette, IN, United States

OPEN ACCESS

Edited by:
*Pierre Echaubard,
SOAS University of London,
United Kingdom*

Reviewed by:
*Henrik Lerner,
Ersta Sköndal University
College, Sweden
Dr. Muhammad Abu Bakr Shabbir,
University of Veterinary and Animal
Sciences, Pakistan
Mo Salman,
Colorado State University,
United States*

***Correspondence:**
*Christina Pettan-Brewer
kcpb@u.washington.edu*

Specialty section:
*This article was submitted to
Planetary Health,
a section of the journal
Frontiers in Public Health*

Received: *29 March 2021*
Accepted: *09 August 2021*
Published: *14 September 2021*

Citation:
Pettan-Brewer C, Martins AF, Abreu DPBd, Brandão APD, Barbosa DS, Figueroa DP, Cediel N, Kahn LH, Brandespim DF, Velásquez JCC, Carvalho AAB, Takayanagui AMM, Galhardo JA, Maia-Filho LFA, Pimpão CT, Vicente CR and Biondo AW (2021) From the Approach to the Concept: One Health in Latin America-Experiences and Perspectives in Brazil, Chile, and Colombia. Front. Public Health 9:687110. doi: 10.3389/fpubh.2021.687110

Professionals throughout the world have been working to assess the interdisciplinary interaction and interdependence between health and wellbeing in a constantly changing environment. The One Health concept was developed to encourage sustainable collaborative partnerships and to promote optimal health for people, animals, plants, the environment, and the whole planet. The dissemination of scientific discoveries and policies, by working directly with diverse communities, has been one of the main goals for Global One Health. The One Health concept has also been referred or related to as "One Medicine, One Medicine-One Health, One World-One Health, EcoHealth," and Planetary Health," depending on each fundamental view and approach. In Latin America, despite the concept still being discussed among health professionals and educators, several One Health initiatives have been used daily for more than decades. One Health action has been applied especially in rural and underserved urban areas where low socioeconomic status, lack of health professionals, and scarcity of medical resources may require professionals to work together. Local communities from diverse social and economic statuses, including indigenous populations have been working with institutions and social organizations for many years, accomplishing results through grassroots movements. These “bottom-up” socio-community approaches have also been tools for the prevention and control of diseases, such practice has preceded the One Health concepts in Latin American countries. It is strongly believed that collaborative, multidisciplinary, political, and economic initiatives with prosocial focus may become investments toward obtaining significant results in the face of global, economic and health challenges; working for a healthier world with inclusivity, equity, and equality. In this study, it is briefly presented how the One Health approach has been initiated and developed in Latin America, highlighting the events and actions taken in Brazil, Chile, and Colombia.

Keywords: one health, ecohealth, planetary health, latin america, indigenous population, saúde única, salud unica, une seule santé

INTRODUCTION

The One Health concept is not a new idea. Although historically, there have been times when medical doctors and veterinarians have worked together (1), it may be much of a generalization to conceive that such collaboration was common in the past. Indeed, one reason why Rudolf Virchow aimed for “one medicine” (later defined as One Health) in the 19th century was actually the lack of doctors and veterinarians working together (2). However, the 20th century brought greater isolation and separation between these two fields of knowledge (1). Considering the current accelerated global development, collaborative efforts and sustainable partnerships in a specific area should contribute to consistent strengths to reach relevant results, with applications directly in the areas studied and into the communities. This process occurred in several fields of global and population health, but the main area in which this idea is highlighted is the scientific research on medical topics.

A scientific and multidisciplinary approach for the health and wellbeing of humans and animals in a balanced environment, which results in the promotion of Planetary Health, showing that everything has been intrinsically connected (3). Also considering the growing interdependence between human beings and domestic or wild animals mainly due to food animal products and human-animal interactions, the medical and veterinary professions have been directed to work together within the collaboration scope toward wellbeing and global health (4). As a result, such an approach has encouraged studies to conduct sustainable partnerships between interrelated groups in different regions and continents to achieve optimal health for people, plants, animals, and the environment. This collaborative effort and holistic approach interactions for global One Health and environmental conservation have involved veterinarians, physicians, public health professionals, educators, anthropologists, environmentalists, and many other professions interconnected with communities. Although sometimes used as synonyms, the terms One Health, One Health approaches, EcoHealth, Planetary Health, One Welfare, and One Wellbeing represent different concepts linked to the same foundation. Some leaders in the field consider that the term, One Health, includes different approaches and differences among them. Since the topic is still controversial and open to discussion, further studies should establish a more stringent use of the said terms, which should be disseminated through teaching and training in all curricula worldwide. Regardless, a comparison of the three holistic approaches to health has been proposed (5), and One Health concepts may be given by practical examples, as already described (6).

ONE HEALTH HISTORY FROM ANCIENT CIVILIZATIONS TO THE 21ST CENTURY IN LATIN AMERICA

History of Health in Latin America Indigenous Population

The perception of health in humans and animals and knowledge of their interconnectedness can be long traced to the traditional knowledge of indigenous people in Latin America. Indeed, animals preceded humans in appearing in the territory by tens of millions of years, they have been deeply interconnected to the history of what is Latin America now. Human appearance has profoundly affected and shaped the health and life of native American animals, which subsequently led to a long history of the increasing human impact: from the Paleoindians, who may have caused the extinction of several Latin American megafauna species, to the Columbian Exchange that brought exotic species from the Old World, such as horses, cattle, sheep, dogs, domesticated American native species including turkeys, llamas, and alpacas, which brought extinction to several native American species. In such a similar dynamic scenario, animals have also influenced human history in an adaptive and interdependent human-animal relationship in Latin America (7).

Montenegro and Stephens (8) have thoroughly described indigenous health in Latin America. They clearly defined two periods of time: before and after the European invasion of the late 15th and early 16th centuries. These Latin American indigenous populations had complex cultures depending on the region they originated. The Inca, Aztec, and Mayan cultures had growing territories with urban populations, political, and military influences. More hunter and gatherer communities around the mountain and rainforests ecosystems were also observed, such as the Guarani in southern parts of South America.

Indigenous populations were neither static nor peaceful. Survival depended on war systems, different weapons, and food strategies. Health and wellbeing were intrinsically connected to sophisticated knowledge acquired through centuries regarding the balanced use of local ecosystems. European invasions changed the culture, inter-ethnic, and ecological relationships of natives. Health was also affected by new infectious diseases. For centuries, since the time of their colonization, conquest, or occupation, indigenous populations of tropical coastal environments suffered the most from illness and poverty. The Central Andes had a demographic collapse similar to the Bubonic plague epidemic in Europe in the 14th century. Later, such native populations have been affected by the continuous spread of diseases, habitat fragmentation, and land occupation associated with the lack of modern health care and infrastructure.

Although the use of animals in conventional medicine has been comparatively recent, a meta-analysis of historical and archaeological evidence indicated that animals have been used in traditional medicine in Latin America since ancient times. This was considered a "faunal drugstore." Animals, mostly wild species, were used as both raw materials for clinically prescribed therapies, and as amulets and charms in native magic-religious rituals and ceremonies (9). Plants have also been used for both human and animal care in South and Latin America (10), demonstrating the environmental health impact on One Health. In contrast, animals have historically threatened human health prior to European arrivals, such as the Yanomami indigenous communities of Northern Brazil, which have been faced with high burdens of native soil, water and food borne zoonoses, including larvae of the native jigger flea, which causes severe disability of hands and feet (11).

Nowadays, many indigenous people still living within isolated environments have been constantly destroyed by non-sustainable agriculture and exploratory business, leading to harsh economic conditions, higher morbidity, and health risks. These populations have been connected and highly dependent on their local ecosystems for survival. Despite the accumulated knowledge and holistic understanding, One Health has much to learn about the early times of native Latin America, as the natural environment deeply influenced indigenous life, culture, and history.

A Modern Historical Perspective of One Health in Latin American Countries

In 2010, the Food and Agriculture Organization (FAO), World Organization for Animal Health (OIE), and WHO collaboration officially established the One Health Tripartite (12). In addition, the European Union reaffirmed its commitment to operate under the One Health umbrella, and in 2011, the first International One Health Congress took place in Australia. In 2014, the International Society for Infectious Diseases (ISID) and ProMED, along with Skoll Global Threats Fund, HealthMap, and Training programs in Epidemiology and Public Health Intervention Network (TEPHINET), began working on another innovative tool for disease surveillance, namely, the EpiCore program. The EpiCore was created to build a network of field epidemiologists and health professionals who could validate reported and suspected disease outbreaks. ProMED moderators send requests for information (RFIs) directly to EpiCore members in a specific area of the world regardless of country or region. The specialties of the EpiCore membership reflect the One Health approach of ProMED with experts in animal, environmental and human health, all represented in the movement (13). Since then, increasing numbers of international organizations have promoted efforts to establish the One Health approach and actions around the world, including in Latin American countries (14–17).

Only in June 2021, at the 168th Session of the Executive Committee that the Pan American Health Organization (PAHO) has included One Health in the official agenda, as a "comprehensive approach for addressing health threats at the human-animal-environment interface" and prioritizing endemic diseases of zoonotic and vector-borne origin, emerging, and reemerging infectious diseases of zoonotic origin, antimicrobial resistance, and food safety (12). However, PAHO has promoted such a multisectoral approach, particularly in veterinary public health, for several decades, back to the Inter-American Ministerial Meeting on Health and Agriculture (RIMSA) in 1968 and 2016, the last entitled as "One Health and the Sustainable Development Goals".

The PAHO proposed analysis and mapping of health interactions in specific national contexts, the establishment of One Health governance, strengthening multidisciplinary and intersectoral aspects, emergency preparedness and response, digital technology and scientific tolls, research, and capacity building as strategies in accordance with Agenda 4.6 One Health of the General Strategic Plan of PAHO for 2020-2025 with an estimated budget of the US $1 million per biennium (12). In that review, the PAHO has indicated a list of collaborating centers and best practices in One Health throughout the Americas, including the Collaborating Center on Environmental and Public Health at Fiocruz in Brazil, with best practices on leptospirosis and rabies approaches, and improvement surveillance on the triple-border area of Brazil-Argentina-Paraguay, and the Chilean Agency for safety and Food Quality (ACHIPIA) in Chile.

ONE HEALTH EXPERIENCES IN BRAZIL, CHILE, AND COLOMBIA

One Health history and development in the last decades in Brazil, Chile, and Colombia have been summarized and presented by timelines of each country (**Figures 1–3**, respectively).

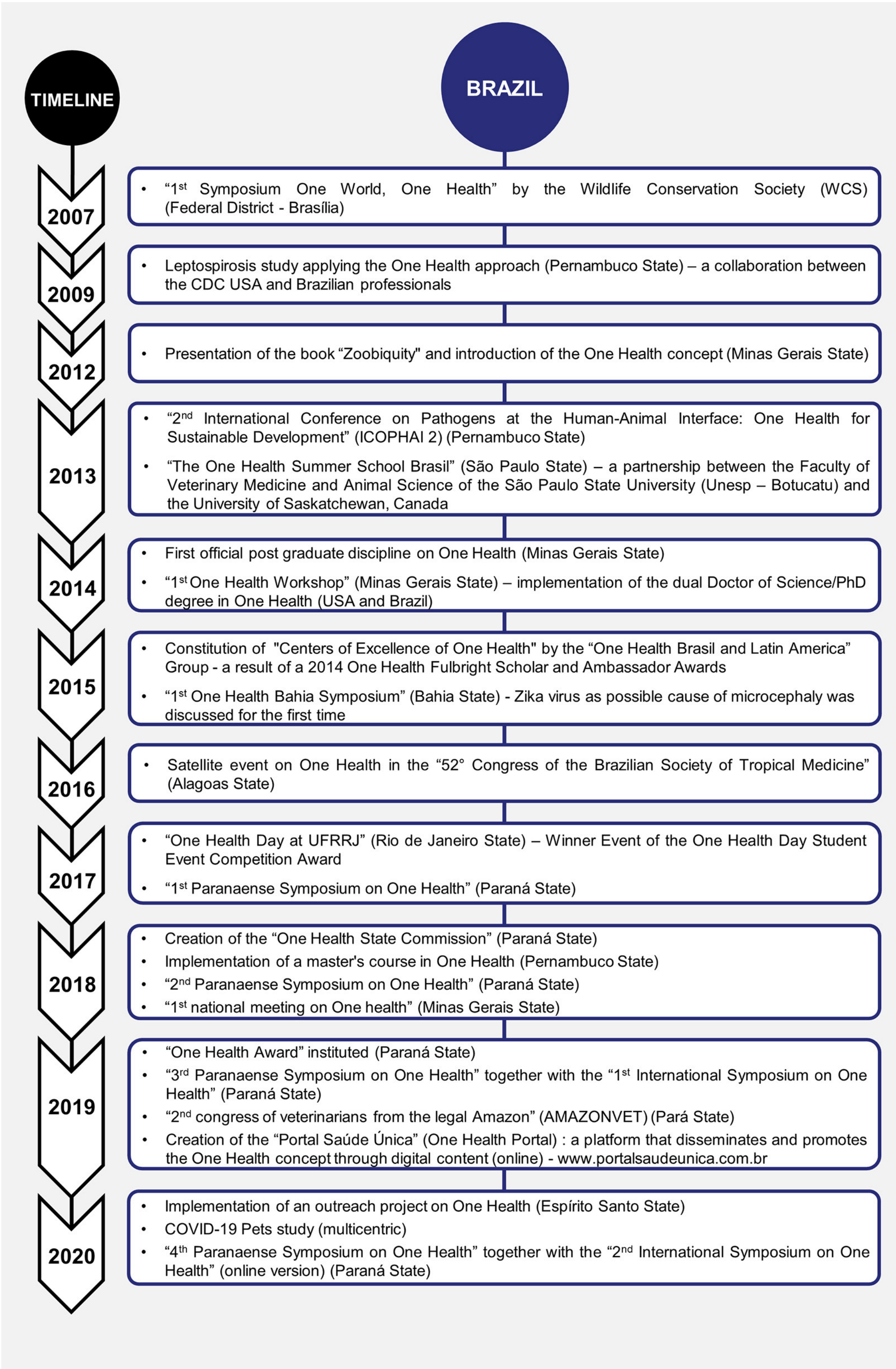

FIGURE 1 | One Health history and development in the last decades in Brazil.

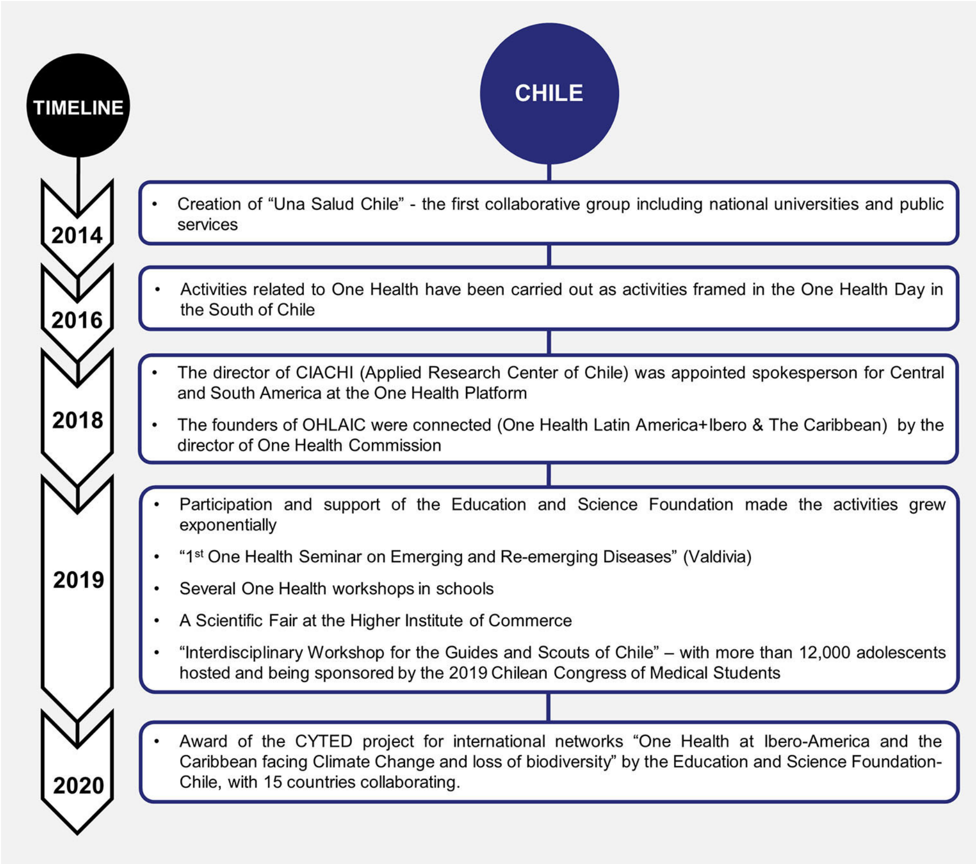

FIGURE 2 | One Health history and development in the last decades in Chile.

One Health in Brazil

From the Approach to the Concept – "Bottom-up" Grassroots Movements

One Health approach in Brazil has been reported long before the term One Health was coined. Since the beginning of Veterinary Medicine and Agriculture Schools in the 20th century, agriculture and health science professionals have been working together in indigenous, rural, and impoverished communities that had no access to health assistance. Conferences held by world organizations in Latin America supported the importance of interdisciplinary actions through Global Health. Wildlife preservation, habitat, and biodiversity topics had been the focus developed from national conservation institutions during the 20th and 21st centuries.

Since 2002, Veterinary Medicine students and residents, at São Paulo State University (Unesp) in Jaboticabal, northeast São Paulo state, Southeastern Brazil, have performed animal and public health outreach in rural communities which would later be regarded as One Health. Students accompanying community health agents assessed health risk factors related to the interaction between humans, animals, and the environment in homes and surrounding areas with attention to the main zoonoses as determinants of the health and disease processes in their ecosystems. Educational actions were applied, mainly, in primary and secondary schools with an expectation that children were the messengers for their parents and their behavior to be changed. All of these activities generate research for postgraduate studies.

The One Health movement in Brazil was officially introduced and recognized in 2007 when Dr. William B. Karesh, a wildlife veterinarian from the Bronx Zoo of New York, EcoHealth Alliance, and the Wildlife Conservation Society (WCS) led the first One Health Symposium in Brazil, introducing the theme "One World, One Health" in which wild animals act as important reservoirs and sentinels of diseases that affect human health being correlated with environmental destruction. In 2009, the Centers for Disease Control and Prevention (CDC) and Brazilian professionals collaborated with a Leptospirosis research study through the One Health approach in Northwestern Brazil. In December 2012, the concepts of One Health, EcoHealth, and Zoobiquity were introduced in Brazil by one of the authors of this study (CPB), who is also a zoo and wildlife veterinarian, by initiating and promoting One Health and spearheading official postgraduate research interdisciplinary programs among national and international academic institutions.

The Veterinary Public Health and Biotechnology (VPH Biotec) Global Consortium launched the "International Congress

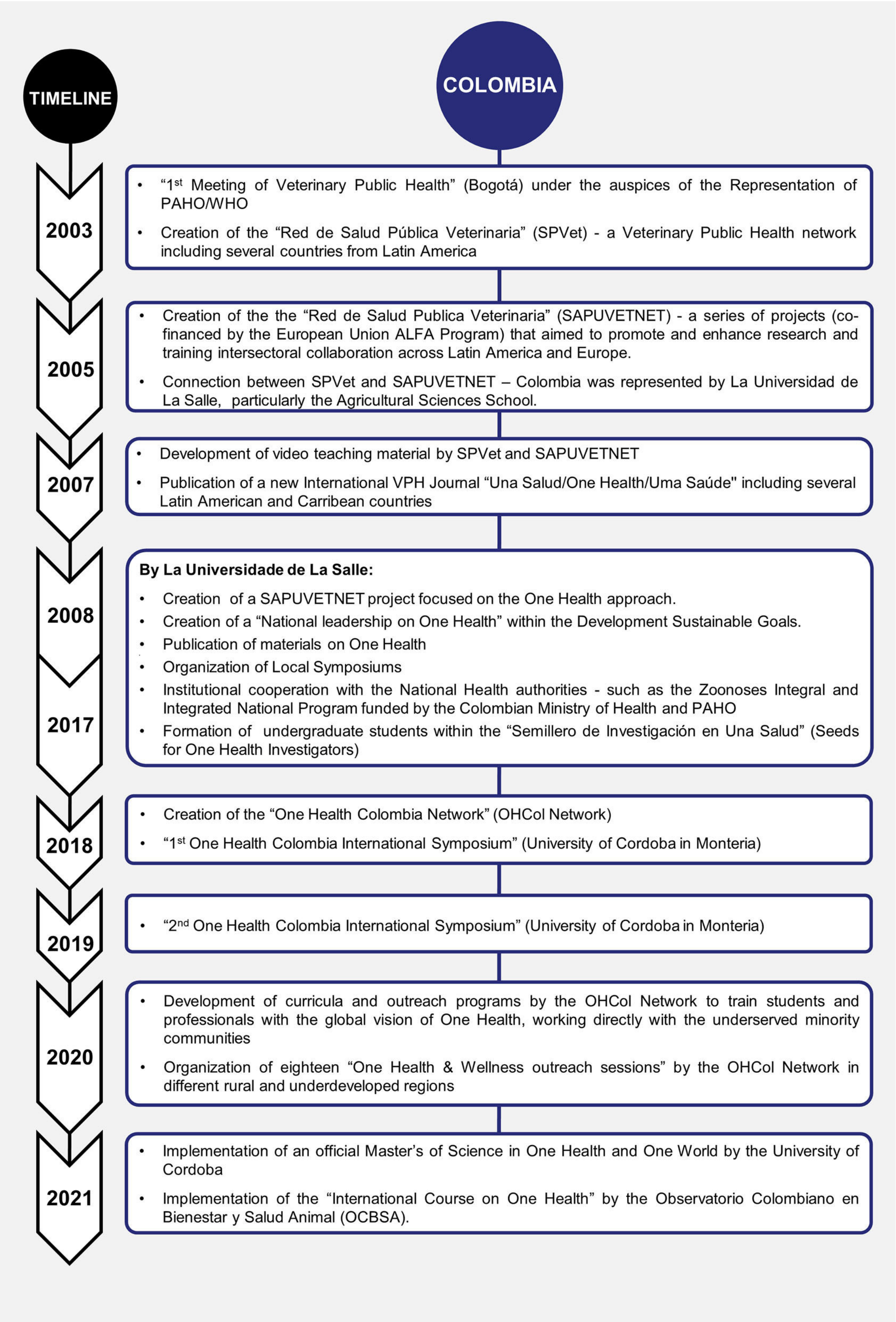

FIGURE 3 | One Health history and development in the last decades in Colombia.

on Pathogens at the Human-Animal Interface (ICOPHAI)." The first edition occurred in Addis Ababa, Ethiopia, in 2011, and the second ICOPHAI was held in Porto de Galinhas, Brazil in 2013 to discuss issues related to zoonotic infectious diseases worldwide and thematic areas that necessitate One Health implementation in Latin America (16).

Since 2012, many One Health events have been officially established in several states and cities in Brazil. Most of the One Health events in Brazil were neither known nor advertised nationally or internationally. The Universities already had interdisciplinary outreach programs with One Health, such as approaches working directly with rural and diverse communities through the Unified Health System ("*Sistema Único de Saúde*" – SUS). By this time, the One Health concept was neither widely known nor advertised nationwide. Similarly, "The One Health Summer School Brazil", which started in 2013, focuses on topics of infectious diseases, food safety, and public policies as part of an international collaboration between the School of Veterinary Medicine and Animal Sciences at Unesp, Prefeitura de Botucatu/SP, and the University of Saskatchewan, Canada. Postgraduate training was developed through international collaborations.

In 2014 and 2015, many actions were carried out in Brazil that contributed to the spread and application of the One Health approach in the country and Latin America. The first One Health Workshop was hosted in Minas Gerais State, Southeastern Brazil with national and international One Health experts (18). In the same year, The One Health Brazil Latin America Group was created and constituted by One Health Centers of Excellence ("*Centros de Excelência de Saúde Única*") as a result of a 2014 One Health Fulbright Scholar and Ambassador Awards, spearheaded by one of the authors of this manuscript. The original Centers of Excellence at the time were held in the states of Bahia, Pernambuco, Minas Gerais, Rondônia, Pará, Roraima, and Mato Grosso do Sul. A successful example of these "grassroots" community and One Health approach movements through "*Centros de Excelência de Saúde Única*" occurred on March 5, 2015, with the First One Health Bahia Symposium held in Porto Seguro with attendance of more than 150 health professionals from different areas and institutions. Infant microcephaly that was possibly associated with the ZIKA virus was presented through the One Health concept by Brazilian physician infectologist, Dr. Antonio Bandeira, working together with Fundação Oswaldo Cruz (FIOCRUZ) and Hospitals. Similar activities involving directly community leaders were developed in these Centers of One Health.

Meanwhile, members of the One Health Brazil Latin America Association presented their work at the One Health Forum in Davos, Switzerland at the third Global Risk Forum One Health Summit 2015 (17), and at the first Global Conference on One Health (GCOH) in May 2015 in Madrid, Spain. This reinforced the commitment to continuing the dissemination of the concept and approach in Brazil and Latin America. The event in Madrid brought together researchers from 40 countries, with the participation of professionals from Brazil and Mexico. Partnerships survey of One Health Brazil Latin America were presented as a reference for several One Health projects in Brazil and Latin America.

The "One Health Brazil Latin America Association" became an official member of the World Veterinary Association (WVA) in 2015. The association included Brazil, Colombia, Peru, and Chile collaborators. Eventually, pioneer members from the Brazilian institutions reorganized and created the One Health Brasil with a purpose to unite, collaborate, organize, and centralize a sustainable multidisciplinary network of One Health, EcoHealth, and Planetary Health in Brazil.

After that, other important initiatives have been promoted, mainly by universities and professional associations like the 52nd Brazilian Society of Tropical Medicine Congress, held in Maceió, Northeastern Brazil in 2016. On this opportunity, the subject "Challenges for human and animal health in transforming ecosystems in a One Health perspective" was widely discussed.

The Centers of Excellence of One Health in Latin America were recognized internationally, supported by the World Veterinary Association (WVA), and the World Medical Association (WMA), receiving several Global One Health Awards in 2016–2017. The "*LeishNão* Project: A One Health approach for visceral leishmaniasis prevention in an endemic area in Brazil" by Galhardo et al. (19), "One Health in Brazil and the One Health International Project Programme" and "From the approach to the concept – a successful "grass root" One Health movement in Brazil and Latin America" by Pettan-Brewer et al. (17), received at the 33rd World Veterinary Association Congress in Seoul, Korea. In November 2016, the WVA, the WMA, the Japan Medical Association (JMA), and the Japan Veterinary Medical Association (JVMA) jointly held the Second WVA-WMA Global Conference (GCOH) on One Health in Japan following the inaugural GCOH held in Madrid, Spain in 2015. The proposal for the third WVA-WMA Global Conference (3rd GCOH) to be hosted in Brazil was presented by the One Health Brazil Latin America representatives and hosted by the One Health Brazil and the Veterinary and Medical Federal Associations. Unfortunately, the event was canceled due to the COVID-19 pandemic.

In February 2017, the antimicrobial resistance (AMR) group from the Pontifical Catholic University of Paraná (PUCPR), using the One Health approach, organized the round table, "Current state of Antimicrobial Resistance in Brazil and the United Kingdom," together with the UK Science and Innovation Network and the School of Life Sciences of PUCPR. They invited 40 high-level experts from the government, academy, and private companies from the UK and Brazil to discuss the global and Brazilian state of AMR. As a result of this round table, several suggestions were made to improve the fight against AMR within the International Global Plan to fight AMR. In addition, the One Health Commission of the Regional Veterinary Council of Paraná State (CRMV-PR), a pioneer at the National level, was formed in April 2018 to fortify Veterinary Medicine in maintaining public, animal, and environmental health under the context of One Health. In 2019, through the State Commission for One Health, a partnership was established between the

Federal and the Regional (PR) Council for Veterinary Medicine, and the first International Symposium on One Health was held, addressing zoonoses, disasters, mental health, and AMR. At the opening of the event, a term of commitment was signed between government entities, PUCPR, and the Regional Council to work in One Health. Thus, the School of Life Sciences (PUCPR), in 2019, changed all the matrices of its undergraduate courses, thus starting with One Health disciplines common to all courses.

After 2017, Federal and Professional Associations (CFMV, CRMV, COREM, CNS, CFM, SBM) have collaborated by disseminating the concept of One Health. The Preventive Medicine and Public Health sectors have always covered aspects of preventing and maintaining the health and wellbeing of animals and, by extension, of human beings. The conservation and preservation of the environment have shown great global interest in health and only in the last decades, with the new emerging diseases, and many enzootic epidemics have been proven to be associated with an imbalance in nature, destruction of habitats, and wild and domestic animals that were sentinels or reservoirs of new epidemics. An example of applying the One Health approach in endemic regions can be seen during the biggest epidemic of Yellow Fever in Brazil, which occurred in the years 2017 and 2018 due to a new cycle wave aggravated by mosquito-borne spreading, habitat encroachment, and exposure of the unvaccinated population. This occurred after almost 80 years of eradication in urban settings by vaccination in 1942. The fatality of wild primates during the epidemic demonstrated the importance of animals as sentinels for human health and the destruction of the environment associated with the reemergence of various zoonotic diseases (20).

Another aspect that highlights the spread of the One Health concept in Brazil and Latin America is the increasing number of events from these countries in the celebration of One Health Day (November 3) in the last years. This international campaign co-coordinated by the One Health Initiative, the One Health Platform Foundation, and the One Health Commission aims to bring awareness to the need for One Health interactions around the world. In 2018, an event organized by students from the Federal Rural University of Rio de Janeiro (UFRRJ) was one of the winners of the One Health Day Student Event Competition Award. The "One Health Day at UFRRJ" brought professionals from different health and environmental-related fields together to sensitize attendees from different backgrounds about the indissociable connection between human, animal, and environmental health. In the last years, similar educational events were held on a local, regional, and national level in Latin America, reinforcing the need for a multidisciplinary approach in many of the contemporary and future challenges.

From 2016 to 2021, other independent health groups continued in formation throughout Brazil and Latin America, such as courses and disciplines. The "1st National Meeting on One Health," in Belo Horizonte, Minas Gerais State, Southeastern Brazil supported by the Federal University of Minas Gerais and Federal Council of Veterinary Medicine (CFMV) aimed to disseminate the concept "One Health," its challenges, policies to professionals in the medical, veterinary, and environmental fields. Most of the One Health groups and events in Brazil initially concentrated on wildlife medicine, species preservation, environmental conservation (Planetary Health and EcoHealth), and emerging infectious diseases in Brazil and Latin America. Many groups focused on sustainable agriculture, agroindustry through the One Health approach, AMR, Food Safety, theater and arts, education, anthropology, and animal and human health, while others focused on comparative medicine and human-animal bond and wellbeing. Several professionals participate in these interdisciplinary partnerships, such as medical doctors, veterinarians, nurses, agronomists, nutritionists, psychologists, historians, anthropologists, statistics, biologists, dentists, conservationists, engineers, artists, and dancers.

Research groups in Brazil have also been applying One Health as a practical tool to solve problems such as zoonoses in different populations and their contact animals, taking advantage of the SUS, which allows comprehensive human-animal sampling. In such scenarios, wild boars, hunting dogs, and hunters have been surveyed in Brazil for vector-borne, waterborne, and foodborne diseases, for the first time worldwide (21). Moreover, One Health research and outreach community projects with community leaders toward Brazilian social classes vulnerability have provided interesting results in animal hoarders, homeless, incarcerated, indigenous, slum, low-income, and traditional island populations in their environments (22–25). In such a hands-on approach, companion and livestock animals have been concomitantly surveyed along with their owners, reaching holistic results, and establishing new roles in pathogen cycles of urban and anthropized settings.

One Health Training, Research, and Outreach in Brazilian Academic Institutions

The increase in the demand for qualification due to the requirements of the labor market has led health, agriculture and environmental professionals to increasingly seek a differential in their academic training with Higher Education Institutions. This fact was specially related to the insertion of different health professional categories, starting from the enactment of Law No. 8,080 of September 19, 1990 (26) in the area of Primary Health Care, more precisely in the Family Health Support Centers, following the publication of the Ministry of Health Ordinance No. 2,488, of October 21, 2011 (27).

Furthermore, the experience of interdisciplinary teaching, research, and extension of Environmental Health at the School of Nursing at Ribeirão Preto, University of São Paulo (SNRP-USP), began four decades ago in the training of clinical nurses. The history of this curriculum development had moments of coming and going, resulting from the institutional didactic and methodological options and trends. However, it took shape and acquired greater consistency over time despite the difficulties imposed by the traditional teaching model centered only on disciplinary practices and the hospital-centered care model. From the 1980s onward, there were important national movements with changes in health care proposals in Brazil, culminating in the promulgation of the new national constitution (1988) and strengthened by the Primary Health Care model and the

SUS in 1990. The creation of an Interinstitutional Group for Studies and Research in Health Service Wastes (IGSRHSW) was strengthened by an interdisciplinary character, composed of professionals from different areas of knowledge and educational institutions, services and assistance in health, environment, sanitation, engineering, economics, and administration focused on Environmental and Planetary Health. Concomitant to the formation of this group, the Environmental Health Laboratory was created, in which an action project was established in the teaching, research, and extension to the community. Academic works were generated, including thesis, dissertations, scientific articles, manuals, books, and book chapters, among others, also offered to graduate students and postdoctoral researchers, opportunities for exchanges with relevant international institutions. Currently, the teaching of Environmental Health at SNRP-USP has been inserted in the teaching practice, in an interdisciplinary way and focused on One Health, through the proposal of building healthy and sustainable environments, aiming at training nurses and other professionals of the future for a globalized world.

In addition, since 2017, the class "One Health: Human, Animal, and Environment" has been offered to undergraduate students at the Federal University of Minas Gerais - UFMG, covering theoretical and practical aspects that include field visits in public parks and zoonosis control services in Belo Horizonte, Minas Gerais.

As previously mentioned, the introduction of the One Health concept in postgraduate education in Brazil was introduced, which was derived from the American term "One Health" and the interdisciplinary approach. The integrated and transdisciplinary training among professionals was brought to the fore among the professors of the Federal Rural University of Pernambuco (UFRPE), which was the utmost need to create and offer a outreach program that would meet the demands required by local communities and by the professionals working together in the Pernambuco State, Northeastern Brazil. Some professors realized in recent years, especially between the period of 2015 and 2018, that students entering postgraduate courses did not have the profile for training in graduate courses at the academic level because the vast majority of them already had employment in a public institution or private company linked to the health, agriculture or environment field, and were often interested in graduate programs mainly to update their knowledge and improve their performance in their professional fields or by their own need for changes in the field of activity in the companies in which they already operated.

In addition to this perception and concern from the professors, and due to the lack of a specific postgraduate program in One Health in the city of Recife, capital of Pernambuco State, the Professional Master's degree in One Health from UFRPE began to be designed and idealized by some professors, who took over the elaboration of the proposal, in the field of preventive veterinary medicine in the Department of Veterinary Medicine. However, since this department did not have enough professors who would meet all the demands of the minimum program content necessary for the training of students, other professors from other departments of the Federal Rural University of Pernambuco (UFRPE) and other institutions, namely, the Federal University of Pernambuco (UFPE) and the Federal University of Agreste of Pernambuco (UFAPE), were invited to collaborate. In addition, considering practical experience and experience in management and administrative positions, professionals from public institutions, such as the State Health Secretariat of Pernambuco, were also invited to compose the teaching staff and contribute to the training of professionals in the field of One Health.

Based on this demand raised by UFRPE, coordinating professors of the developing proposal have scheduled meetings with the various segments and institutions linked to the One Health field, such as municipal and state health departments and the Agricultural Defense Agency of the State of Pernambuco. The Defense Agency, in particular, readily showed interest and positively signaled support for the creation of a postgraduate course in the One Health field in addition to raising actions among their staff. This was done for training and updating, given the growing demands and needs from society for joint action of quality by the professionals who make up the staff of the respective companies. Thus, the implementation of a professional master's course in the field of? One Health at UFRPE was a demand needed not only by veterinary medicine professionals and other health professionals, given the different possibilities of performance in the professional market, but also by the society itself. This was done for technically qualified professionals to meet their needs, as food consumers and users of different health services, related to health surveillance, a better quality of life, animal health defense, environmental health, and primary health care.

Currently, the accredited professional master's degree in One Health at UFRPE has two lines of action and/or intervention called Surveillance and Primary Health Care and Epidemiology and Health Planning. Teaching staff formed by veterinarians, an economist, a dentist, a speech therapist, and, occasionally, professionals from other areas were invited to interact with the students, among which included social workers, nurses, physiotherapists, veterinarians, an administrator, a pharmacist, biologists, educators, among other professionals, who develop intervention projects in their institutions of origin, whether public or private, in the field of health, agriculture, and environment, related to health education, control of communicable or non-communicable diseases, water, food, management, processing of epidemiological data, AMR, among others at the intersection human, animal, and environment.

The design of shared disciplines at the post-graduate level by applying the Collaborative Online International Learning concept has also been an initiative to promote One Health among different professionals in Brazil and other countries (28). The Federal University of Espírito Santo (UFES), in partnership with Federal University of Paraná (UFPR), and universities from Mozambique (Catholic University of Mozambique), Germany (Ludwig Maximilian University of Munich - LMU - and Technical University of Munich), and Kosovo (Kolegji AAB), developed the "Joint Initiative for Teaching and Learning on Global Health Challenges and One Health" (JITOHealth) in 2020, financed by the Center for International Health at

LMU. The JITOHealth targets education and training, focusing on surpassing the lack of collaborative approach, absence of cross-cultural experiences, and unequal distribution of scholarly resources in One Health, with experts from 22 institutions of the Americas, Africa, Europe, and Asia collaborating with the course content.

Outreach projects in higher education institutions also support the promotion of One Health among faculty, scholars, and communities in Brazil. An interdisciplinary team from UFES, recognizing the importance of training professionals in the One Health approach, created an outreach project entitled One Health ES in 2020, which involves faculty, professionals, and undergraduate and graduate students of different areas, such as medicine, veterinary, nutrition, pharmacy, biology, biomedicine, and dentistry. Periodically, the group meets to debate publications involving One Health and to plan and develop projects to be implemented in the community aiming at the health promotion and the prevention and control of diseases by applying the One Health concept, such as publication of informative material in social media. One Health ES also organizes webinars with invited experts, improving the network for further projects. The team also conducts research using this approach working directly with communities, which has been promoted in the social media of One Health ES. The engagement in the interprofessional actions, with collaborative participation of the entire team, highlights the promising impact of this initiative in the public health system and biodiversity in Brazil.

In Minas Gerais, Southeastern Brazil, the Post-Graduate Research Program (PPG) of the Federal University of Viçosa has been a program of international research partnerships with the University of Washington and The Paul Allen Global Animal Health at the Washington State University, the USA with an official dual Doctor of Science and PhD. The UFV/UW/WSU One Health interdisciplinary post-graduate partnership program continues to support sustainable collaborative research projects in One Health approaches as well as hosting exchange of professionals, students and visiting scholars.

During the COVID-19 pandemic, veterinarians in the Residency Program at UNESP Jaboticabal have been working directly in Public Health on different fronts of action both in Epidemiological Surveillance and Primary Health Care, as well as in the Coronavirus Service Center, performing telemonitoring of suspected patients. In parallel, two research projects have been developed: "Seroprevalence of SARS-CoV-2 infection in the municipality of Jaboticabal - SP: serial serological surveys" and "Molecular diagnosis of patients infected with SARS-CoV-2 in the municipality of Jaboticabal - SP: use of a safe and low-cost protocol." Also, due to a departmental reorganization at the School of Agricultural and Veterinary Sciences, a Department of Pathology, Theriogenology and One Health has been renamed, demonstrating that One Health should be accepted as a reality that involves all disciplines related to animal health and global health, in the interface with the environment, including One Health in the curriculum, outreach, and research.

One Health Brasil (OHB) Network History

As regional One Health groups were created, mainly through articulations in favor of research opportunities, but also for specific events, university professors and post-graduate students from different professional programs established a small online community in 2016 using the mobile platform, WhatsApp that would have become the most popular in Brazil and several countries. They established this community, the One Health Brasil Network, together with leaders and members of the One Health Brazil Latin America Association and several other One Health commissions and groups from all over Brazil. Initially, such a network aimed at simply sharing contacts and general information, intuitively associated with the themes of One Health, EcoHealth, and Planetary Health, from newspaper and scientific academic articles, policy reports, manuals, and regulations to advertise lectures and world events related to One Health.

Growing "organically," especially from the outreach promoted by its members at symposia and conferences, the community began to face one of the great challenges of a community-based organization: effective communication. Often, the dialogical space was taken by manifestations that, although relevant, clearly diverged from the One health approach and, often, conveyed ideological positions and political readings of governmental programs and actions. With the recurrence of circumstances impairing constructive and collaborative dialogue, the necessity of a group management committee became clear. This management committee then started monitoring the posts and, whenever necessary, intervening to preserve the focus on One Health and, as much as possible, the predominance of collaborative attitudes.

In 2019, the management committee decided to create a website to what was already called the Rede One Health Brasil network (29), as a project. The creation of the website, itself, became an opportunity for the committee to enunciate the fundamental identity aspects of the organization, namely, its mission, vision, values, and strategic objectives. Next, the distribution of attributions and responsibilities in the first cycle of strategic planning was postponed with the emergence of the COVID-19 pandemic in the first quarter of 2020. On the one hand, One Health gained greater visibility from the global crisis. On the other hand, the process of consolidating presential partnerships and collaborations into new institutions seems to have been suspended, awaiting resumption in 2021. However, online meetings, lectures, discussion panels, and live webinars were happening daily. One Health Brasil network has been a successful example to all other countries of inclusive and sustainable interdisciplinary partnerships that unite a country through national and international collaborations. The network has established mutual official partnerships with organizations such as One Health Platform, One Health Initiative, One Health Commission, and One Health Sweden, continuing to build solid partnerships among uncountable international organizations from all continents. One Health Brasil also has thematic groups, such as ECOHA (*Ecossistemas Aquáticos: Saúde animal, humana e Ambiental*), an interdisciplinary subdivision applying One

Health, EcoHealth, Planetary Health, and wellbeing of all lives in aquatic ecosystems.

In 2020, through the One Health Brasil network, investigators from different regions of Brasil received a CNPq Research Award (PetCOVID-19 Study applying the One Health approach) and have been leading the first SARS-CoV-2 research in pets in Latin America. Results have been notified to OIE-WOAH, peer-reviewed articles have been published, and education through media and internet tools have been emphasizing the importance of veterinarians as essential professionals in human health, animal welfare, and the prevention and control of pandemics through One Health.

One Health in Chile

In 2014, the first initiatives of One Health began in Chile, forming the first collaborative group (*Una Salud Chile)* including national universities and public services (30). Subsequently, since 2016, some activities related to One Health have been carried out as activities framed in the One Health Day on November 3, which were reproduced in the South of Chile.

Later in Santiago, the education team of the Center for Applied Research of Chile (CIACHI) wanted to provide education in civil society and directly in the communities, working and consolidating the resilience of the villages within Santiago. On December 4, 2018, the director of CIACHI was appointed spokesperson for Central and South America at the One Health Platform and the director of One Health Commission connected the founders of OHLAIC. The activities grew exponentially throughout the year in Chile with the participation and support of the Education and Science Foundation. The First One Health Seminar on Emerging and Re-emerging Diseases was held in Valdivia, several One Health workshops in schools, and a Scientific Fair at Higher Institute of Commerce were carried out (31). Furthermore, an interdisciplinary workshop for the Guides and Scouts of Chile with more than 12,000 adolescents was hosted and sponsored by the 2019 Chilean Congress of Medical Students (32). In 2020, the first course in the world for non-biologist undergraduate students on One Health (law, psychology, journalism, and engineering) was given at the Adolfo Ibáñez University with excellent comments from students (33).

The main purpose of the National One Health Network (ReNOH) has been to connect all One Health groups in Chile to work based on local, national, and global objectives, including researchers and university students working in the same areas from all regions of the country. It is currently incorporating high school students and civil society, bringing the concept to schools and civic associations such as neighborhood councils or fairs.

The expansion of ReNOH has been a work in progress and discovery of new activities, in this context. Their main objectives have been to educate in One Health concepts and strategies, reaching the most remote and vulnerable communities (34). The main challenges for the groups that currently work in One Health in Chile have been to coordinate public policies under this concept and generate a greater national closeness and understanding of the scope of this strategy for university students of various careers and society in general, where until now there has been low penetration of the concept.

One Health in Colombia

The history of the One Health approach in Colombia has also been linked to Veterinary Public Health teachings from the beginning of the 21st century. Professionals from several cities of the country gathered under the "*Red Salud Pública Veterinaria*" (SPVet). The SPVet network was created following a recommendation made at the First Meeting of Veterinary Public Health held in Bogotá (Colombia) in 2003 under the auspices of the Representation of PAHO-WHO. Organizations and Universities participating in this meeting included the National University of Colombia, Antioquia University, and the District Secretary of Health. During this meeting, an important dialogue related to food safety, prevention of zoonoses, poor public perception of the role of veterinarians in the wellbeing of the community, low importance of veterinary public health in higher education, and absence of guidelines for professional practices and the consequent fragmentation of the agricultural sector in the decision-making regarding the health system and the social and economic development of the country was held. The objectives of the SPVet network were the following: (1) maintaining a continuous and timely flow of information on veterinary public health topics, (2) strengthening ties of cooperation and support among specialists, create a space for discussion and consultation on topics of national interest as international, and (3) contributing to the strengthening of undergraduate and graduate academic activities in veterinary public health (35).

The need to integrate the improvement of professional activity and education in public health added to the need for veterinarians to take part in certain situations of emergencies affecting the relationship between humans and animals. This led to the development of the "*Red de Salud Publica Veterinaria*" (SAPUVET), a series of projects co-financed under the EU ALFA program, aimed to support an international network constituted by Faculties of Veterinary Medicine from Latin America and Europe. The projects have envisaged a series of objectives and activities aimed to promote and enhance research and training and intersectoral collaboration across Latin America and Europe. Project partners use a mail-list and distance learning platforms (e.g., Moodle, Colibri) to organize educational activities. Major results so far achieved have included the harmonization or development of a common curriculum, the creation of common modules on selected VPH topics, and that new teaching methodologies were used for a common training program on VPH, delivered *via* the Internet, using the problem-solving approach based on case studies. Challenges were experienced as a result of poor and unreliable internet connections. The use of modern communication and teaching methods in combination with written and theoretical material enabled lecturers and students at the universities involved to test, in some cases, for the first time, a problem-solving approach and a modular teaching structure in virtual format of real situations. The adoption of this innovative, flexible, less teacher-dependent mode of learning has played a key role in the activities of the network (36). Production of videos (DVDs) and self-learning software (CD-ROM) on meat inspection and hygiene (in three languages), development of an online VPH teaching Manual (beta version in Spanish), organization of e-conferences on upcoming VPH issues, publication of a new International VPH Journal "*Una Salud/One Health/Uma Saúde,*" (in three languages) exchanges of professors and researchers and coordinating meetings, participation in and organization of seminars, congresses, and conferences at the National and International level, and the publication of scientific and popular articles were used. The SAPUVETNET didactic tools have been tested and used by partner faculties and universities and other institutions. Didactic material can be freely circulated and distributed, used for distance learning, and be adapted to the local context of any country or geographical area, even outside Latin America and Europe (35–38).

The University representing Colombia in the SAPUVETNET project was La Universidad de La Salle, particularly, the Agricultural Sciences School, located in Bogotá. The school has been active for the past 10 years in (i.) publishing academic material, (ii.) promoting the One Health concept through participation and organization of local symposiums, (iii.) institutional cooperation with the National Health authorities such as the Zoonoses Integral and Integrated National Program funded by the Colombian Ministry of Health and Pan American Health Organization, and (iv.) formation of undergraduate students within the *Semillero de Investigación en Una Salud* (Seeds for One Health Investigators) (39, 40).

Another important network applying the One Health approach not only in the academic field but also in general communities is the University of Córdoba in Monteria, northern Colombia. This University constituted the One Health Colombia Network (OHCol Network) being recognized nationally and internationally by One Health Commission (USA) and the International Student One Health Alliance (ISOHA). This Institution held the first One Health Colombia International Symposium in 2018 and the second One Health Colombia International Symposium in 2019. The OHCol Network has been accredited as an official member of the interdisciplinary alliance for research and international collaborative training with the Schools of Medicine and Global Health, and the One Health Research Center (COHR) at the University of Washington, USA, and have been developing curricula and outreach programs to train students and professionals with the global vision of One Health, EcoHealth, and Planetary Health approaches for conservation and human, animal and environmental health among the underserved minority communities. Colombian health professionals working with research and community leaders through the One Health approach were also members of the original One Health Brazil Latin America Association which has been officially a member of the World Veterinary Association since 2015.

Since 2018, the One Health Colombia Network has held 18 "One Health and Wellness outreach sessions" in different rural and underdeveloped regions. More than 1,200 animals of several species have been evaluated, vaccinated, vitaminized, and dewormed. In addition, more than 7,000 people of all ages have received medical care and educational teachings in prevention health and welfare. These outreach sessions follow a human-animal-environmental interface methodological strategy based on Human Health activities, Biodiversity, and Economics Health (41). From 2020 to 2021, OHCol has developed One Health and One Welfare programs with institutions with other Latin American countries and also with One Health Centers from Colorado, Alaska, and Italy. An official Master's of Science in One Health and One World has been accredited at the University of Cordoba.

Under the COVID-19 pandemic, several Colombian public health research groups have published about the importance of the One Health Approach in the emergence of newer zoonotic infections like SARS-CoV-2 (42, 43). Authors have pointed out the potential of several zoonotic infections that calls for the implementation of One Health as a framework to design and operationalize better public health programs. Some of these groups were (i) the Epidemiology and Public Health Research Group at the De La Salle University in Bogotá, (ii) the Biodiversity and Ecosystem Conservation Research Group (BIOECOS), at the Fundacion Universitaria Autonoma de las Américas in Pereira, (iii) the Public Health and Infection Research Group, Faculty of Health Sciences, at the Universidad Tecnológica de Pereira, (iv) The Fundación Universitaria Agraria de Colombia (*Uniagraria*) located in Bogotá, v. CES University, Medellín, and vi. the National University of Colombia, located in Medellín and Bogotá.

One of the most significant contributions from the Colombian National Health Institute was the launching of the One Health Zoonotic Disease Prioritization workshop (OHZDP) in Bogotá in August 2019, based on the methodology developed by the CDC USA and Colombia (44).

In November 2019, the second International One Health Symposium held by the One Health Colombia and leaders from One Health in Latin America countries (Chile, Costa Rica, Cuba, Uruguay, Brazil, and others) signed a One Health Latin America Manifest for mutual understanding committing to work collaboratively and synergically within the One Health Latinoamérica, Ibero y el Caribe network (OHLAIC) (45).

One Health in Latin America Ibero and Caribbean Network (OHLAIC)

Despite the adaptation of an English-speaking concept of One Health to Spanish, Portuguese, or French of most Latin American countries, the majority of terms can be easily translated due to their link to basic words describing almost the same health issues. However, Latin languages accept the switch of substantive-adjective. For example that "One Health" (*Saúde Única*, *Salud Unica*, *Une Seule Santé*) and "Health One" (*Uma Saúde*, *Una Sola Salud*, *Une Santé*), may be interchangeable in such languages.

One Health in Latin America arose after many researchers asked themselves why this concept was remarkably familiar and had not officially entered Latin America. The mutual experiences were that it was due to idiosyncrasies, language barriers, political and economic difficulties. For this reason, individual countries started building and strengthening One Health Networks with professionals who already were working with a One Health approach without distinction of race, creed, political ideology but inclusive networks at no cost and with the consideration that in Latin American countries the budgets for research and education were very low. Hence, each country in Latin America has different experiences and the history of each one remains to be fully described. The objectives and goals of the One Health Latin America, Iberic, and Caribbean countries network have been detailed and presented in **Figure 4**.

In 2019, a "*Quien es Quien*" *in One Health in Latin America* Webinar was presented and hosted by the One Health Commission with over 17 countries representing Latin America and the Caribbean Islands (46). In December 2019, the Network OHLA (sounding as Hello! in Spanish or Portuguese) grew with the addition of Spain and Portugal, changing its original name to OHLAIC to include Ibero and Caribbean countries (47). In April 2020, the OHLAIC webinar cycle began with the first Webinar "Reflections on the COVID-19 pandemic from the vision of One Health and One Welfare" (48) continuing in July 2020 with the second webinar "COVID-19: SARS-CoV2 disease and wildlife in Latin America" with excellent exhibitors and a large audience. Thus, consolidating a network with clear objectives and that in December 2020 a CYTED project (Ibero-American program of science and technology for development) was awarded for thematic networks on the subject of sustainable development and climate change for 4 years (49). Recently, during December 8–11, 2020, SAPUVETNET-OHIN and Latin American Universities held a webinar series organized by the Universidad Peruana Cayetano Heredia in Lima presenting multiple results of research studies within the One Health Approach.

Next Steps for One Health in Latin America and the Caribbean With the World

The One Health in Latin America, Ibero, and Caribbean Network has presented specific objectives which have been gathered, summarized, and presented in **Figure 4**. However, the specific goals of One Health networks in Latin America rely on each country and their prioritized actions. In such One Health approach, main goals have been accomplished by collaborative synergism and non-competitiveness, sensitizing different society actors, culture inclusiveness and diversity, and practical multidisciplinary working groups. The objectives of these One Health networks in Latin America have prioritized actions from a collaborative synergism and non-competitiveness to work from a One Health approach to sensitize the different actors of society and to form working international groups in the different areas of global health. It has served as a platform for meeting and bringing together different professionals linked to different areas of human, animal, and ecosystem health, and for allowing the exchange of not only scientific knowledge, but also the union of different cultures, thoughts, and initiatives around One Health. There has been a great importance to interculturality in such a way as to know the roots of all Latin Americans and try to preserve them and keep them active over time, even more so now to generate a new deal with the ecosystems as the native peoples did with respect, equality, passion, and wisdom.

Another main objective of such networking is the establishment of a standard system for the joint assessment of international infectious disease risks, construction of sustainable mechanisms for collaboration and communication between the bodies and ministries responsible for human health and animal health, and align national, regional, and international strategies. This is to prevent and control diseases with collaboration and participation in an intersectoral initiative implementing the concept in daily practice. One Health offers a systematic approach to complex problems that involve interactions between spheres of human-animal-environmental health. This approach has been increasingly important in an era of rapid changes in the environment, including climate change. It requires new types of transdisciplinary collaboration, direct participation with local communities to conduct integrated assessments, and interventions that consider the interconnected health of humans, animals, and the environment. As described in the introduction, One Health terms represent different concepts linked to the same One Health foundation. However, it has been essential to continue the discussion for the welfare of human beings and animals, the connection between all (One Welfare; One Wellbeing) (50) and the complex integration of One Health, Health of the Environment (EcoHealth), Economics Health, and Health of the Planet (Planetary Health) as a remarkable continuing global agreement by all countries following its 17 Sustainable Development Goals and 169 targets for the future health of the planet and all life on it (51, 52).

DISCUSSION

To further develop the One Health concept, we must consider taking into account the accelerated advances in science and the globalization of our economies. This has been important because about 75% of emerging infectious diseases have been shared between humans and domestic and/or wild animals. Emerging zoonotic diseases that affect Latin American countries today result from interactions between natural and human-animal-plant systems. Infectious agents, such as *Salmonella* spp., *Escherichia coli*, tuberculosis, malaria, yellow fever, influenza A(H1N1), West Nile Virus, Zika, Dengue, Chikungunya, and SARS-CoV-2, have been examples in which animals, humans, and the environment have been intrinsically related. In these cases, animals were also victims of the emerging infectious diseases transmitted by vectors being sentinels for human health and a sign of an imbalance in the environment, especially by habitat destruction due to deforestation or pollution. In addition, emerging or neglected zoonotic diseases, such as hantavirus pulmonary syndrome, leptospirosis, trypanosomiasis (Chagas disease caused by *Trypanosoma cruzi* and other species), brucellosis, hanseniasis, treponemas, and leishmaniasis arose when human beings have invaded forest region, increasing the contact between people wild animals who might act as pathogen reservoirs. A better understanding of the type of contact between human and animal populations (domestic or wild) has been

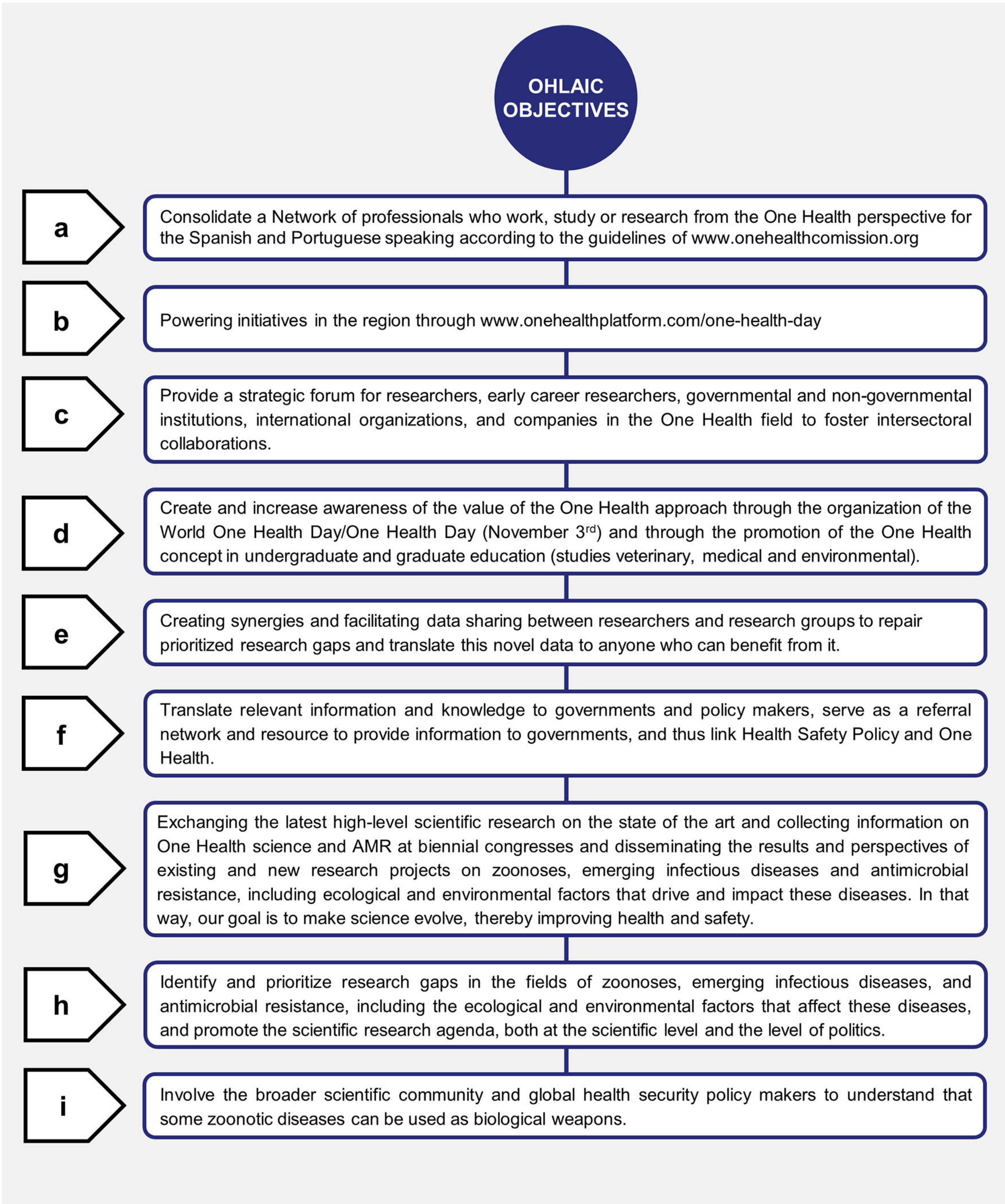

FIGURE 4 | The objectives and goals of One Health Latin America, Iberia, and Caribbean Network.

fundamental for modeling how zoonotic infections will emerge and spread. The emergence of several unidentified species of new pathogens in Latin America and co-infection with *Bartonella*, *Ehrlichia*, and *Rickettsia* as possible etiologic agents of anthropozoonoses and zooanthroponoses, and related diseases in pets, livestock, and wildlife have intensified the interest in neglected and emerging pathogens.

Zika, dengue, hanseniasis, leptospirosis, leishmaniasis, yellow fever, parasitic and other neglected diseases in Brazil, and the complex nature of emerging zoonotic diseases demonstrated the need to strengthen even more interdisciplinary training and partnerships elucidating the concept of One Health in Latin America and support the work with indigenous tribes and underprivileged communities. As a result of collaborative efforts supported by Latin America's One Health, networks have developed and organized national teams for disasters preparedness through One Health. On February 11, 2021, Latin American representatives from the WHO contacted the One Health Brasil network executive members to collaborate in the submission of a proposal for the importance of One Health in Pandemics, Food Safety, Food Security, and Bioterrorism.

The emergence and spread of diseases with sustained transmission from person to person have long hit humanity, representing challenges for science and public health, worldwide. Changing natural environments can modify the balance between species, increase contact between them and establish human-animal bridges. Other activities, such as wildlife trafficking, incorrect use of soil or water, urbanization without sustainability, habitat destruction, lack of basic sanitation, fires and deforestation, and the absence and/or breaking of health protocols can also contribute to the emergence of new diseases. Although governments have been responsible for public health policies, the multifactorial character in the emergence of pandemics means that the responsibility for controlling those that have been occurring, and for preventing new ones from arising, be that of all professionals, or future professionals, and of citizens living in a community. It has been the role of collaborative efforts to promote discussions and generate and disseminate knowledge, fulfilling their role in the training of professional citizens, since only knowledge can lead to changes in habits and behaviors of individuals and society.

One of the challenges, foremost, in the academic scientific world is to understand the importance to work together equally with the native and minority populations of Latin America by listening to what these ancient cultures have to teach the scientists and not vice versa. Politics, years of lack of trust built among conflicting cultures, excessive bureaucracy and biased government policies from these countries interfere with collaborations and research partnerships to be developed. The One Health approach creates a unique effort to promote Unity in Diversity, cultural coexistence, human-animal-plant-ecosystem harmony, and spiritual universal values. Their Unity in Diversity concept that we share the same sky, walk the same Earth, breathe the same air, and that we are a single family might bring resolution for successful partnerships in a more holistic health vision. This unity is the essence of life from ancient civilizations and indigenous peoples which must be learned, as animals and the natural environment have deeply influenced indigenous life, culture, and history, in an adaptive and interdependent relationship throughout Latin America.

The recent experience of Latin America with COVID-19 has demonstrated the importance of a more interconnected world through cooperative and less competitive collaborations. One Health may be the way for preventing future pandemics and health disparities instead, focusing on health equity, environmental and economic sustainability. Not surprisingly, through One Health initiatives, veterinarians with all professions have been associated at the front response of COVID-19 pandemics. One Health may represent the main future strategy and basis for preventive actions requesting veterinarian leadership, as potential unknown animal pathogens may still become emergent in human beings (53, 54). Latin America has been an example of "hands-on" One Health actions for a more inclusive and healthier Planet from the approach to the concept with more equal representation.

There were some limitations to this review. Primarily, the review has relied mostly on personal knowledge of authors and search of main selected events instead of a formal "One Health" systematic review, a relatively new concept word in Latin America which would fail to provide a comprehensive search of both indexed and non-indexed studies, experiences, and events. Although the authors have focused the review on only three Latin American countries, such an international approach has not been published to date, and it may stimulate and inspire future interactions and publications by One Health researchers in neighboring countries worldwide. Thus, the review herein has aimed to establish a starting point by rescuing the history and current efforts on One Health initiatives in only three out of the 33 countries currently established in Latin America and the Caribbean to date.

Importance of One Health

Although the past topic has offered a detailed discussion about One Health experiences and conferences held at different times, the importance of One Health should be described separately. The strengthening of national and international collaborative partnerships in elucidating the concept of One Health by sharing experiences in conferences and during on-field practical actions has led to a better implementation of the One Health approach and measures to mitigate, control and prevent emerging and infectious diseases, such as Zika, dengue, hanseniasis, leptospirosis, yellow fever, antibiotic-resistant bacteria and parasitism, and the complex nature of diseases in indigenous and underprivileged communities in many Latin American countries.

The One Health approach supports global health security by improving coordination, collaboration, and communication at the human-animal-plant-environment interface to address shared health threats, such as zoonotic diseases, antimicrobial resistance, food safety and security among others. Examples of potential benefits and outcomes of One Health actions are to monitor and develop standards at the local, national and global health equity, ensure adequate capacity in health including strategies to prevent, detect and respond to outbreaks of diseases, develop emergency preparedness responses, support interdisciplinary collaborative partnerships, and control of highly infected pathogens and reemerging diseases, and conduct scientific research.

One Health is an inclusive collaborative, multisectoral, and transdisciplinary approach, working at the local, regional, national, and global levels, with the goal of achieving optimal health outcomes recognizing the interconnection between people, animals, plants, and their shared environment. Furthermore, the Importance of a One Health approach has increased in advancing global health security and the Sustainable Development Goals.

Finally, improvement of international, national, regional and local levels of One Health networking and collaborative research studies, associated with professional training, conferences, and continuing education, has led to a better understanding of the human-animal interactions (domestic or wild) and spatial modeling on emerging, reemerging, and spreading of zoonotic infections. The advance of One Health in concepts and approaches in such a holistic way has provided key tolls for prevention and preparedness, as already presented at the discussion for tuberculosis, malaria, yellow fever, influenza A(H1N1), West Nile Virus, Zika, Dengue, Chikungunya, and recently for SARS-CoV-2.

CONCLUSION

Independent of the approach used to describe the link and vision of Health of the Environment (EcoHealth), Economics Health, Health of the Planet (Planetary Health), and Population Health to One Health, all these concepts share the same goals as understanding their use as practical holistic tools for better and more effective solutions to address threats to the health, wellbeing and sustainability of humans, animals, plants and the environment. Above all, One Health can be used as a preventive measure for upcoming threats not only for Latin America but for the shared planet Earth as a whole.

Based on local "grassroots" demands, action movements and population needs, the experiences of One Health history and development in Latin America and Caribbean countries are different from other continents, from within the same continent like North America, and even among the three Latin American countries discussed herein. This review hopes to inspire other countries, regions, and continents to also share their own One Health experiences.

While the One Health approach worldwide is considered crucial to address governance challenges of complex issues and is widely supported in theory, its implementation in practice remains limited, especially due to lack of financial support and the secular anthropogenic and self-centered mentality. Altogether, the world must continue working to further establish a standard system of equal assessment of health, construction of sustainable mechanisms for collaboration and communication between responsible agencies and ministries for human, plant, and animal health. Furthermore, align national, regional, and international strategies with collaboration, cooperation, and intersectoral partnership implementing the concept of environmental conservation in daily practice. Not only to learn and change the paradigms of health and diseases, of economic-political-cultural crises for the conservation of the Planet's Biodiversity with inclusion, equity, and sustainability with a holistic view, but also change our Ego into the Eco framework. Finally, there is a critical need to respect, rescue, and learn from diverse communities and indigenous peoples who have the ancestral knowledge for a balanced life on our planet. Thus, future One Health experiences in Latin America should always associate cross-disciplinarity action and concept, surpassing political, social, cultural, and linguistic differences.

AUTHOR CONTRIBUTIONS

All authors contributed equally, approved the submitted version, and collaboratively to the written manuscript. CP-B designed the original manuscript. Figures were designed by DF, CV, NC, and AB. AM, DA, DSB, DFB, DF, AB, and CV finalized the review.

FUNDING

The University of Washington Faculty grant 75-5324 PETTAA was applied for publication fees.

ACKNOWLEDGMENTS

We acknowledge all the pioneers and groups in Latin America and Caribbean countries for their valuable contributions and initiatives in One Health. Due to space limitations, we certainly missed references and events, and we encourage future publications with the history and experiences of each country. We also acknowledge the valuable contributions from One Health Paraná Commission, One Health Brasil Network, One Health Latin America Ibero & Caribbean, International Student One Health Alliance, and the valuable work of Dr. Antonio C. Bandeira, Dr. Jane Megid, Dr. Diego Soler, Dr. Maria Nely Cajiao, Jorge Gonzales Meza, One Health Colombia members, and Dr. Sergio Scott.

REFERENCES

1. Bresalier M, Cassidy A, Woods A. One health in history. In: *One Health: The Theory and Practice of Integrated Health Approaches*, eds Zinsstag J, Schelling E, Whittaker M, Tanner M, Waltner-Toews D. (1st ed. Oxfordshire, CAB International). (2015). p. 1–14.
2. Wilkinson L. *Animals and Disease: An Introduction to the History of Comparative Medicine*. Cambridge University Press. (1992)
3. American Veterinary Medical Association. One Health: A New Professional Imperative. (2008) Available online at: https://www.avma.org/sites/default/files/resources/onehealth_final.pdf
4. Calistri P, Iannetti S, L Danzetta M, Narcisi V, Cito F, Di Sabatino D, et al. The components of 'one world - one health' approach. *Transbound Emerg Dis.* (2013) 60:4–13. doi: 10.1111/tbed.12145
5. Lerner H, Berg CA. Comparison of three holistic approaches to health: one health, ecohealth, and planetary health. *Front Vet Sci.* (2017) 4:163. doi: 10.3389/fvets.2017.00163
6. Lerner H, Zinsstag J. Towards a healthy concept of health. In: Zinsstag J, Schelling E, Crump L, Whittaker M, Tanner M, Stephen C, eds. *One Health: The Theory and Practice of Integrated Health Approaches*. Oxfordshire: 2nd Ed, CAB International (2021). p. 52–57. doi 10.1079/9781789242577.0052
7. Vergara G. Animals in Latin American history. In: *Oxford Research Encyclopedia of Latin American History.* (2018). doi: 10.1093/acrefore/9780199366439.013.436
8. Montenegro RA, Stephens C. Indigenous health in Latin America and the Caribbean. *Lancet.* (2006) 367:1859–69. doi: 10.1016/S0140-6736(06)68808-9
9. Alves RR, Souto WM. Ethnozoology in Brazil: current status and perspectives. *J Ethnobiology Ethnomedicine.* (2011) 7:22. doi: 10.1186/1746-4269-7-22
10. Alves RN, Barboza RRD, Souto WDMS. Plants used in animal health care in south and Latin America: an overview. (2010). Available online at: https://

www.taylorfrancis.com/chapters/mono/10.1201/EBK1420045604-15/plants-used-animalhealth-care-southand-latin-america-david-katerere-dibungi-luseba?context=ubx&refId=7e4e76c7-0179-4e7d-9a43-0e0f43d38ac1
11. Ehrenberg JP, Ault SK. Neglected diseases of neglected populations: thinking to reshape the determinants of health in Latin America and the Caribbean. *BMC Public Health.* (2005) 5:119. doi: 10.1186/1471-2458-5-119
12. PAHO. CE168 / 13, Rev.1. (2021) One Health: a comprehensive approach for addressing health threats at the human-animal-environment interface. Available online at: https://www.paho.org/en/documents/ce16813-rev-1-one-health-comprehensive-approach-addressing-health-threats-human-animal
13. Carrion M, Madoff LC. ProMED-mail: 22 years of digital surveillance of emerging infectious diseases. *Int Health.* (2017) 9:177–83. doi: 10.1093/inthealth/ihx014
14. Mackenzie JS, McKinnon M, Jeggo M. *One Health: From Concept to Practice, in Confronting Emerging Zoonoses*. Tokyo: Springer Japan. (2014). p. 163–89. doi: 10.1007/978-4-431-55120-1_8
15. Kahn LH. *One Health and the Politics of Antimicrobial Resistance. Emerging Infectious Diseases*. Baltimore: John Hopkins University Press. (2016)
16. Gebreyes WA, Dupouy-Camet J, Newport MJ, Oliveira CJB, Schlesinger LS, Saif YM, et al. The global one health paradigm: challenges and opportunities for tackling infectious diseases at the human, animal, and environment interface in low-resource settings. *PLoS Negl Trop Dis.* (2014) 8:e3257. doi: 10.1371/journal.pntd.0003257
17. Pettan-Brewer C, Rabinowitz PM. *Histórico e Abordagem Clínica das Doenças Infecciosas pela Abordagem da One Health. Chapter 5.* Doencas Infecciosas na Pratica Clinica. Eds: AP Gomes, PSB Miguel and R Siqueira Batista. Editora Revinter. (2020)
18. One Health International Partnership Programme. (2014) Available online at: http://www.onehealth.ufv.br. (accessed 14 March 2021).
19. Association WV. Short summary of WVA activities during WVC2017. (2017) Available online at: http://www.worldvet.org/uploads/news/docs/1_overview_activities__wvc2017.pdf
20. Silva NIO, Sacchetto L, de Rezende IM, Trindade GDS, LaBeaud AD, de Thoisy B, et al. Recent sylvatic yellow fever virus transmission in Brazil: the news from an old disease. *Virol J.* (2020) 17:9. doi: 10.1186/s12985-019-1277-7
21. Kmetiuk LB, Krawczak FS, Machado FP, Paploski IAD, Martins TF, Teider-Junior PI, et al. Ticks and serosurvey of anti-Rickettsia spp. antibodies in wild boars (Sus scrofa), hunting dogs and hunters of Brazil. *PLoS Negl Trop Dis.* (2019) 13:e0007405. doi: 10.1371/journal.pntd.0007405
22. Gravinatti ML, Faccini-Martínez ÁA, Ruys SR, Timenetsky J, Biondo AW. Preliminary report of body lice infesting homeless people in Brazil. *Rev Inst Med Trop.* (2018) 60:8–9. doi: 10.1590/s1678-9946201860009
23. Felipetto LG, Teider-Junior PI, da Silva FFV, Yamakawa AC, Kmetiuk LB, do Couto AC, et al. Serosurvey of anti-toxoplasma gondii antibodies in homeless persons of São Paulo city, Southeastern Brazil. *Front Public Health.* (2020) 8:732. doi: 10.3389/fpubh.2020.580637
24. Cunha GR da, Pellizzaro M, Martins CM, Rocha SM, Yamakawa AC, Silva EC da, et al. Spatial serosurvey of anti-Toxoplasma gondii antibodies in individuals with animal hoarding disorder and their dogs in Southern Brazil. *PLoS ONE.* (2020) 15:e0233305. doi: 10.1371/journal.pone.0233305
25. Benitez A do N, Monica TC, Miura AC, Romanelli MS, Giordano LGP, Freire RL, et al. Spatial and simultaneous seroprevalence of anti-leptospira antibodies in owners and their domiciled dogs in a major city of Southern Brazil. *Front Vet Sci.* (2021) 7:1–15. doi: 10.3389/fvets.2020.580400
26. BRASIL. LEI N° 8.080, DE 19 DE SETEMBRO DE 1990. (1990). Available online at: http://www.planalto.gov.br/ccivil_03/leis/l8080.htm
27. BRASIL. PORTARIA N° 2.488, DE 21 DE OUTUBRO DE 2011. (2011) Available online at: http://bvsms.saude.gov.br/bvs/saudelegis/gm/2011/prt2488_21_10_2011.html
28. Vicente CR, Jacobs F, Carvalho DS, Chhaganlal K, Carvalho RB, Raboni SM, et al. Creating a platform to enable collaborative learning in One Health: the joint initiative for teaching and learning on global health challenges and one health experience. *One Health.* (2021) 12:100245. doi: 10.1016/j.onehlt.2021.100245
29. One Health Brasil network. (2019). Available online at: https://www.onehealthbrasil.com (accessed 20 October, 2020).
30. Canals M, Cáceres D. Una Salud: conectando la salud humana, animal yambiental. *Cuad Médico-Sociales*. (2020) 60:9–21. Available online at: http://www.saludpublica.uchile.cl/noticias/176718/una-salud-conectando-la-salud-humana-animal-y-ambiental (accessed August 24, 2021).
31. One Health Education in Chile (2019) Available online at: (https://ciachi.org/es/taller_oh_feria_cientifica_insuco2//. (accessed 14 March, 2021).
32. One Health and Medical Education in Chile (2019) Available online at: https://cocem.cl/. (accessed 14 March, 2021).
33. Cianfagna M, Bolon I, Babo Martins S, Mumford E, Romanelli C, Deem Sh L. et al. Biodiversity and Human Health Interlinkages in Higher Education Offerings: A First Global Overview. *Front Public Health.* (2021) 9:637901. doi: 10.3389/fpubh.2021.637901
34. Figueroa D, Duprat X. Remedying anthropogenic zoonoses. *Anim Sentience.* (2020) 30:2018–20. doi: 10.51291/2377-7478.1666
35. Ortega C, Villamil LC, Cediel N, Rosenfeld C, Meneghi D de, Rosa M de, et al. Las redes SAPUVET y SPVet: un modelo de integración en materia de salud pública veterinaria entre Europa y América Latina. *Rev Panam Salud Pública.* (2005) 17:60–5. doi: 10.1590/S1020-49892005000100011
36. Ortega C, Parilla G, De Balogh K, Rosa M De, Gimeno O, Estol L, et al. New approaches for education and training in veterinary public health: the SAPUVET projects. *J Vet Med Educ.* (2007) 34:492–6. doi: 10.3138/jvme.34.4.492
37. Ortega C, De Meneghi D, Balogh de K, De Rosa M, Estol L, Leguia G, et al. Importancia de la salud pública veterinaria en la actualidad: el proyecto SAPUVET. *Rev Sci Tech l'OIE.* (2004) 23:841–9. doi: 10.20506/rst.23.3.1527
38. De Meneghi D, Bert E, Porporato P, Pattono D, Cediel N, Vilhena M, et al. The SAPUVETNET Projects: experiences of intersectoral collaboration and research/training in veterinary public health across Latin America and Europe. *G Ital di Med Trop.* (2011) 16:93–101. Available online at: http://www.simetweb.eu/document/3633
39. Benavides-Arias D, Soler-Tovar D. Priorización de enfermedades virales zoonóticas en la interfaz de cerdos silvestres, cerdos domésticos y seres humanos. *Biomédica*. (2016) 36:56–68. doi: 10.7705/biomedica.v36i0.2950
40. Cediel Becerra NM, Hernández Manzanera J, López Duarte MC, Herrera Buitrago P, Donoso Burbano N, Moreno González C. Empoderamiento de las mujeres rurales como gestoras de los Objetivos de Desarrollo Sostenible en el posconflicto colombiano. *Equidad y Desarrollo*. (2017) 1:61–84. doi: 10.19052/ed.4077
41. Carrascal Velásquez JC, Pettan-Brewer KC, Pastrana Puche N estella, González Meza JH, Botero Serna YP, Figueroa D, et al. 2nd One Health Colombia International Symposium OHCIS2019. (2019). Available online at: https://repositorio.unicordoba.edu.co/bitstream/handle/ucordoba/2532/LIBRO DE RESÚMENES OHCIS2019.pdf?sequence=9&isAllowed=y
42. Bonilla-Aldana DK, Holguin-Rivera Y, Perez-Vargas S, Trejos-Mendoza AE, Balbin-Ramon GJ, Dhama K, et al. Importance of the One Health approach to study the SARS-CoV-2 in Latin America. *One Heal.* (2020) 10:100147. doi: 10.1016/j.onehlt.2020.100147
43. Bonilla-Aldana DK, Ruiz-Saenz J, Martinez- Gutierrez M, Tiwari R, Dhama K, A Jaimes J, et al. Concerns on the emerging research of SARS-CoV-2 on felines: could they be significant hosts/reservoirs? *J Pure Appl Microbiol.* (2020) 14:703–8. doi: 10.22207/JPAM.14.SPL1.04
44. One Health Zoonotic Disease Prioritization Workshop Available online at: https://www.cdc.gov/onehealth/what-we-do/zoonotic-disease-prioritization/fact-sheet.html. (accessed 14 March, 2021).
45. nd International One Health Symposium Proceedings Available online at: https://repositorio.unicordoba.edu.co/handle/ucordoba/2532. (accessed 14 March, 2021).
46. Who's is who in One Health in Latin America. One Health Commission (2019). Available online at: https://www.onehealthcommission.org/index.

cfm/37526/96819/quien_es_quien_en_una_salud_en_america_latina___whos_who_in_one_health_in_latin_america_ohla_webinar
47. OHLAIC Network. Available online at: www.ohlaic.org (accessed 14 March, 2021).
48. OHLAIC Webinars. Available online at: https://ohlaic.org/es/event/webinar_2020_1/ (accessed 14 March, 2021).
49. CYTED Available online at: http://www.cyted.org/es/noticias/redes-y-proyectos-aprobados-convocatoria-2020. (accessed 14 March, 2021).
50. Jordan T, Lem M. One Health, One Welfare: education in practice veterinary students' experiences with Community Veterinary Outreach. *Can Vet J.* (2014) 55:1203–6.
51. Rabinowitz PM, Pappaioanou M, Bardosh KL, Conti L. A planetary vision for one health. *BMJ Global Health.* (2018) 3:e001137. doi: 10.1136/bmjgh-2018-001137
52. Evison W, Bickersteth. The Business of Planetary Health from Economic Theory to Policy and Practice. Chapter 16 Planetary Health – Protecting Nature to Protect Ourselves by Editors S Myers and H Frumkin. Island Press 2020. doi: 10.5822/978-1-61091-967-8_16
53. Fathke RL, Rao S, Salman M. The COVID-19 pandemic: a time for veterinary leadership in one health. *One Health.* (2020) 11:100193. doi: 10.1016/j.onehlt.2020.100193
54. de Melo RT, Rossi DA, Monteiro GP, Fernandez H. Veterinarians and one health in the fight against zoonoses such as COVID-19. *Front Vet Sci.* (2020) 7:1–5. doi: 10.3389/fvets.2020.576262

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

frontiers in Public Health

PERSPECTIVE
published: 29 September 2021
doi: 10.3389/fpubh.2021.649355

Social Sciences in One Health: Insights From Multiple Worlds Perspectives on the Dam Rupture in Brumadinho-Brazil

Ana Pérola Drulla Brandão[1], Stefanie Sussai[2], Jéssica Alves de Lima Germine[3], Diego Duarte Eltz[4] and Aline Araújo[5]*

[1] Department of Preventive Medicine, Faculty of Medicine, University of São Paulo, São Paulo, Brazil, [2] Department of Preventive Veterinary Medicine and Animal Health, Faculty of Veterinary Medicine and Animal Science, University of São Paulo, São Paulo, Brazil, [3] Graduate Program in Human and Social Sciences, Federal University of ABC, Santo André, Brazil, [4] Graduate Program in Social Anthropology, Federal University of Rio Grande do Sul, Porto Alegre, Brazil, [5] Graduate Program in Social Sciences, University of Vale do Rio dos Sinos, São Leopoldo, Brazil

OPEN ACCESS

Edited by:
Christina Pettan-Brewer,
University of Washington,
United States

Reviewed by:
Margot Winifred Parkes,
University of Northern British Columbia Canada, Canada
Nicole Redvers,
University of North Dakota,
United States

***Correspondence:**
Ana Pérola Drulla Brandão
anaperola@alumni.usp.br

Specialty section:
This article was submitted to
Planetary Health,
a section of the journal
Frontiers in Public Health

Received: 04 January 2021
Accepted: 30 August 2021
Published: 29 September 2021

Citation:
Brandão APD, Sussai S, Germine JAL, Eltz DD and Araújo A (2021) Social Sciences in One Health: Insights From Multiple Worlds Perspectives on the Dam Rupture in Brumadinho-Brazil. Front. Public Health 9:649355. doi: 10.3389/fpubh.2021.649355

Concepts that integrate human, animal, and ecosystem health - such as One Health (OH) - have been highlighted in recent years and mobilized in transdisciplinary approaches. However, there is a lack of input from the social sciences in OH discussions. This is a gap to overcome, including in Latin America. Therefore, this paper incorporates recent studies from economics and anthropology to the debate, contributing to the opening of transdisciplinary dialogues for the elaboration of OH theory and practice. As a starting point, we explore the recent case of a tailings dam breach, making considerations about how and why this event was experienced in different ways by the affected Indigenous and non-Indigenous worlds. From economics, we show how different theories perceive and impact these different worlds, presenting some existing alternatives to the hegemonic thinking of domination and exploitation. From anthropology, we present the perspectivism concept, deriving from the field of relational ontologies, suggesting there are significant and inevitable disagreements-equivocations-among different worlds. Thus, we discuss how the social sciences can help address challenging factors that need to be considered in health approaches that intend to deal with complex global problems. In conclusion, OH should incorporate social science discussions, considering relating practice to the multiple realities in which a particular problem or conflict is inserted. Overcoming the barriers that hinder transdisciplinary dialogue is fundamental and urgent for an effective approach to the multiple and distinct interconnections among humans, animals and environments.

Keywords: alternative economy, equivocations, extractivism, Indigenous worlds, one health, perspectivism, pluriverse, transdisciplinarity

INTRODUCTION

In recent years, some holistic health perspectives such as One Health, EcoHealth, and Planetary Health have grown in importance, and their concepts have undergone a process of constant refinement. Some differences between these terms have been studied and described, such as their origin and central focus, the sciences contributing to each of them, and how they value humans, animals and ecosystems (1). However, despite their differences, a common aspiration is toward integrative, collaborative, transdisciplinary, and multisectoral approaches that acknowledge the health of people, animals and the environment as "one" (2–7).

In common, such concepts also express a disagreement with the traditional Western thinking that radically separates and opposes nature and humanity. Thus, pairs of opposites like nature/humanity - among others derived from it, such as physical/metaphysical, objective/subjective, humanity/animality - has underpinned the way Western thinking understands nature (including animals) and relates to it, also reflecting how health and disease are differentiated. Therefore, the modern world winds up limiting entire ecosystems to an object, a resource to be controlled and managed to satisfy human needs.

This way of thinking led to what is conventionally called the *Anthropocene* (See **Panel 1** for the glossary of terms used in this paper) (8). One of the factors that characterizes this new geological era is the expansion of mineral, oil and biotechnological extraction. These large-scale extractive activities have harmful impacts that are not homogeneously produced or distributed among the different strata of society. Besides, such impacts affect the health of people, animals and ecosystems (9, 10). Therefore, the effects of the Anthropocene on the planet are an issue to be considered by integrative health discussions (5).

Considering the holistic health perspectives, health and disease are no longer understood solely as qualities or conditions of an isolated individual - whether human or not - but rather, of a multispecies collective living in the Anthropocene epoch. From this assertion, it is clear that the social sciences can contribute to such health debates, since they focus on the interplay of humans, society, and nature.

Focusing on the *One Health* concept **(Panel 1)**, early aspirations about the potential to address both social and ecological concerns have made landmarks and driven following studies since (2, 11). The significant role but also the underrepresentation of the social sciences have been described in recent years (12–14). Despite some initiatives, such as the efforts of the One Health Commission (15), this lack is still significant. Particularly in Brazil, the scientific publications using the term One Health have been mostly limited to the sphere of veterinary science and public health. This fact, which we consider to be a problem, is certainly multi-causal, but is also due to the strength of the disciplinary divisions that configure the scientific practices in the country.

With the paucity of social science perspectives within the One Health space, this current article therefore aims to contribute to the opening of *transdisciplinary* dialogues **(Panel 1)** in the elaboration of One Health theory and practice in Brazil - and in other Latin American countries that could benefit from this integration. Utilizing a particular event as an example and starting point, we present *challenging factors* **(Panel 1)** from studies and recent discussions in economics and anthropology that exemplify the need for transdisciplinary discourse.

STARTING POINT: TAILINGS DAM RUPTURE IN BRUMADINHO, MINAS GERAIS STATE, BRAZIL

In January 2019, a tailings dam operated by Vale S.A., the world's largest iron ore producer (16), collapsed in the municipality of Brumadinho. Nearly 13 million m^3 of iron ore tailings (17) reached the tributaries of the Paraopeba River, part of the São Francisco Basin: one of the main watersheds in the country. The toxic mud traveled along the river, causing irreversible ecosystem damages, and affecting several other municipalities, including Indigenous territories such as the Pataxó Hã-hã-hãe and Kaxixó (18) (**Figure 1**). A total of 259 people died and 11 are still missing and assumed dead (19). The impacts of the tragedy are certainly far-reaching and long-lasting, and the socio-environmental damages are systemic, synergistic, and dynamic, involving the health, environment, economics and rights of people, animals and affected areas (20, 21).

This tragedy occurred just 3 years after a similar one in the same region, in the municipality of Mariana, when another dam-co-owned by Vale-released 45 million m^3 of iron ore tailings, reaching the tributaries of the Doce River and then the Atlantic Ocean. Since then, the company was aware of the risk of failure of the dam in Brumadinho, which means that the disaster was not natural and could have been avoided (17).

From this context and its consequences, we bring for reflection two very different statements about what happened. The first came from Vale's CEO: "Vale is a Brazilian jewel that cannot be condemned for an accident that happened in one of its dams, no matter how great its tragedy may have been" (22). The second one came from the Chief of the Naô Xohã village, where 25 Pataxó Huh-hã-hãe families lived: "It was a funeral without a wake. A piece of our body was cut off" (23).

These statements exemplify how and why events like this can be experienced and understood in different ways by the Indigenous and non-Indigenous worlds. For the mining company and the Brazilian government, the damage to the Paraopeba River represents an *externality* **(Panel 1)** that cannot compromise development. For the Pataxó Hã-hã-hãe Indigenous people, the river is not only what Western thinking understands as nature, but also a part of themselves - the watercourse is also a life course. Based on this context as a starting point, this paper relies on theories and discussions of economics and anthropology to suggest there are significant disagreements among *multiple worlds* **(Panel 1)**.

ECONOMICS: HOW DIFFERENT THEORIES PERCEIVE AND IMPACT MULTIPLE WORLDS

In the statement by Vale's CEO, expressions such as "accident" and "cannot be punished," refer to the hegemonic economic thinking that treats environmental impacts as negative externalities. In this respect, externality refers to "side effects" arising from productive or consumption actions (24), that is, factors external to the system (25). In this case, the private

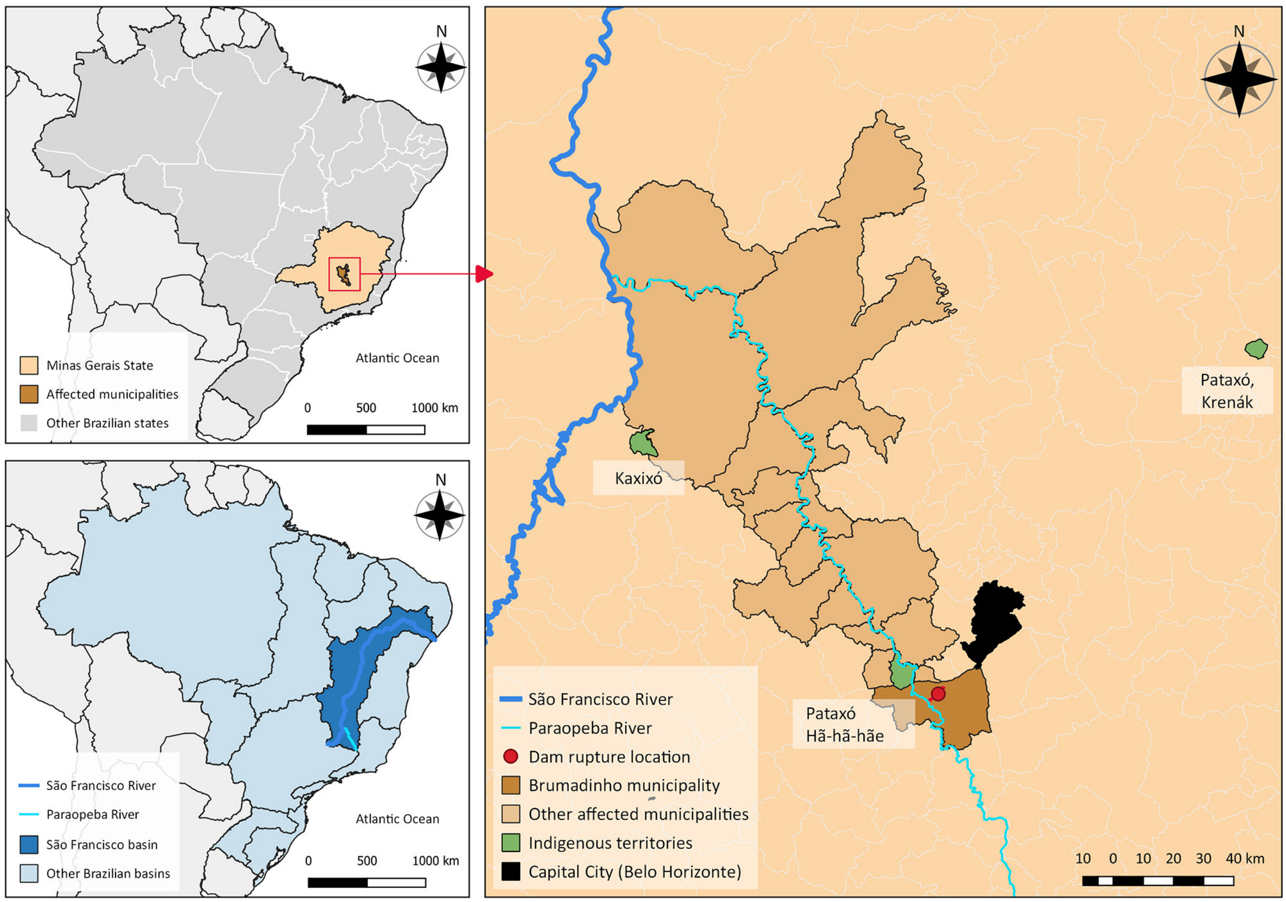

FIGURE 1 | Location of Brumadinho dam rupture, showing the extension of the impact on rivers, municipalities, and Indigenous territories.

benefits of the company's activities, measured in monetary terms, were prioritized to the detriment of the socio-environmental costs of the dam rupture, which cannot be precisely quantified.

In this productive system, the notion that "a river is a water pipe and animals are protein factories" (26) has become institutionalized. Since private property is a key element, the *common goods* - those shared by everyone and that do not belong to an individual or group, such as what is called natural resources- can be 'managed' and tend to be overused, generating a negative externality to the environment or society.

For Vale, as well as for the entire economy derived from classical and neoclassical theories, the workable solutions offered to minimize such effects are limited to the creation of taxes and subsidies or some kind of "externality market." Then, in theory individuals can negotiate the costs derived from their activities (25, 27). Therefore, it is common for the mining, agriculture and tourism sectors to measure their impacts in monetary terms. However, it is impossible to attribute value to the lost lives, or to the socio-environmental impact caused - including the death of an entire river.

In this sense, two phenomena create and intensify the disastrous ecological scenario. The first is the dual and hierarchical perception of the world (such as human and nature). This is a way of justifying and legitimizing relations of domination, whether among humans or between humans and other-than-humans. The second is the fictions derived from traditional economics and imposed as absolute truths. These fictions are responsible for legitimizing and establishing economic fundamentalism as hegemonic, such as the idea that production is unrelated to life (26).

Alternative economic theories have emerged in opposition to the traditional ones and can enrich the dialogues with One Health since they question the idea that nature is just an object or resource. The *political ecology* focuses on socio-environmental conflicts, proposing the integration of indicators to broaden the view of the consequences of economic development in different populations and territories (28). The *ecological economy* contests the meaning of development and its implications, going beyond the concept of sustainable development and proposing an alternative to it. In addition, it presents multicriterial strategies allied with environmental policies to deal with such effects, such as the so-called externalities (29). The *theories of degrowth* presuppose a break with the production and consumption system based on capitalist domination and exploitation, through self-limitation and moderation (30), and abandonment of unlimited economic growth (31).

In this direction, we cannot fail to mention the idea of *buen vivir* - good living - born in Latin America and influenced mainly by Andean and Amazonian Indigenous roots. Buen vivir is a plural concept conceived by the confluence of theoretical debates, Indigenous practices, social movements, and political constructions (32). Also, buen vivir questions the concept of well-being based on Eurocentric assumptions, defends overcoming the idea of development as a synonym for material accumulation, and offers alternatives to it (33, 34). The principles of buen vivir were formalized in the new Constitutions of Ecuador and Bolivia, as a fundamental base of the State.

Therefore, the alternative to the current scenario would be to overcome dualisms, admitting eco-dependence and interdependence, as well as placing life at the center of economics and politics (26), in order to build a possible non-domination system. In this sense, we introduce and explore a field of anthropology called *relational ontologies* **(Panel 1)**, which shows that the dualistic ontology (that radically separates nature from humanity), despite its universal claim, is not the only one (35).

ANTHROPOLOGY: WHEN ASSUMPTIONS ARE NOT COMMON - OR THE SAME - AMONG WORLDS

The studies of relational ontologies concern the interrelationships of a broad community - considering community as a concept that "initially human-centered, is expanded to include other-than-humans" (35). Situating the practices of modernity in space and time, the relational ontologies demonstrate that not all worlds are made from the same divisions, such as human/other-than-human or culture/nature.

One example of relational ontology studies is *perspectivism*, formulated by Viveiros de Castro in 1996 (36). It has become one of the most cited concepts in Brazilian anthropology, and also is the most notable theoretical contribution to global anthropology (37). The term "perspectivism" comes from philosophy and was borrowed to highlight a striking aspect of Amerindian worlds: the way human beings see animals and other subjectivities is profoundly different from the way these beings see humans and themselves.

The notion of other-than-human beings having their own perspective comes from a great mythical division (36, 38, 39) that is "shared by several, if not all, Indigenous people of the New World," as is stated by Viveiros de Castro (40). According to de Castro (41), unlike the Western evolutionary vulgate - which uses soul and, more recently, consciousness or culture as criteria to distinguish humanity from animality - the Amerindian perspectivism states that the original condition of other-than-human beings is humanity, not animality. Their bodies, as we see them, are clothes that hide their internal human form, which is only visible to those of the same species or trans-specific beings, such as shamans. Thus, back in their homes - as the humans they are - they hunt, fish, fight, and perform rituals. If we start to see from their perspective, it means that our soul has been stolen or that we are being taken to a different world (41).[1]

The perspectivism discussion confronts the modernistic idea that there is only one shared world - one external and objective reality - and multiple representations of it, i.e., worldviews or cultures. The modern way of thinking enables cultures to be hierarchized according to how distant their representations are from that one reality. Such hierarchy allows a specific culture to have the privilege and monopoly of defining terms such as nature, culture, humanity, animality, health and disease (42). Instead, the perspectivism points to a *pluriverse* - multiple worlds that share the same culture, and even use the same terms, but differ according to the perspective of the referent, whether human or other-than-human. Thus, there is no privileged perspective to define reality.

Since these multiple worlds are not based on the same assumptions and divisions, there may be significant disagreements between them. In that respect, a category of perspectivism arises called *equivocations* **(Panel 1)**, which emerges when different worlds use the same term to refer to different things. Because these equivocations are a result of a communicative relationship between different worlds, they express an ontological relationship and not an epistemic misconception (43).

We believe the Brumadinho catastrophe can illustrate an equivocation. As previously exemplified, for the Indigenous world, the Paraopeba River was a life course. This *uncommon*[2] status of the river is unacceptable for the modern world. For Vale and the Brazilian State, a river is not - and cannot be - different from a hydrographic formation, a formless universally shared *common good* that can be managed and exploited as an externality (44).

Since equivocations emanate from different worlds, they cannot be avoided. However, they can be controlled[3] by a communicative exercise that considers the referential otherness of the different perspectives, maintaining and communicating their ontological differences (45, 46). This exercise invites us to think of a *common alternative*, namely "the expression of an ecology of divergent practices, constantly negotiating what would be their common interest" (44). Therefore, we suggest that identifying equivocations and being open to this communicative exercise can be a key element in any integrative health approach.

[1] In a classic illustration in this regard, Viveiros de Castro stated that jaguars, seeing themselves as humans, see humans as tapirs or wild pigs, so for them, our blood can be beer. If humans start to see the blood of his relatives as beer, taking the perspective of jaguars, this means that we are being taken to a different world to turn into a jaguar.

[2] The term "uncommon" - as used here - comes from the discussions of the anthropologist Marisol de la Cadena (44). In this context, the expression refers to a status of what is not universally shared, that is, of what is not the same among worlds.

[3] According to the anthropologist Eduardo Viveiros de Castro, in the perspectivism theory, to control an equivocation means to listen and speak knowing that the referents are different. That is, the difference between terms must be communicated and controlled in the dialogue. In symmetric humanity, to control equivocations is a way to preserve life (45).

DISCUSSION

One Health professionals and researchers often address complex health phenomena and recognize the importance and need of integrating different fields of knowledge. The collaboration among disciplines can be imagined and carried out in diverse ways and with different objectives, as shown by the concepts of multi-, inter-, meta-, pluri- and transdisciplinarity (47–49). The last (and most complex) seeks knowledge *between*, *through,* and *beyond* disciplines, without a hierarchical relationship among them (50).

In Brazil, transdisciplinarity in health has advanced since the 1970's, with two historical movements that emerged in the context of fighting for democracy and against the military dictatorship that lasted from 1964 to 1985. The first was the Brazilian Health Reform, resulting in the creation of the Unified Health System [SUS (Portuguese acronym)] (51). The second was the political-ideological-intellectual movement of Collective Health, resulting in a whole new field of health studies and practices (52). In the 1990's and 2000's, transdisciplinarity became more widespread after the SUS implemented its Family Health Strategy, with multi-professional teams working to promote health beyond the hospital environment (53).

However, in Brazil there are still many barriers that hinder knowledge sharing and unification, such as historical institutional structures, values and habits (54, 55). These obstacles, imposed by modernity, can manifest themselves as "social, pedagogical, ideological, political, psychological, methodological and technical" (54). Therefore, overcoming these barriers is a challenge additionally for professionals and researchers who seek to act within the realm of One Health.

Our starting point - the analysis of the dam rupture - provided elements that relate to some recent discussions in economics and anthropology. Such discussions are an example of the undeniable contribution of the social sciences to One Health issues, since they highlighted the existence of *challenging factors* - such as huge environmental impacts considered as mere externalities and the existence of equivocations between different worlds. These challenging factors need to be seriously considered by health approaches that intend to be integrative, since they increase the awareness of the complexity of health topics.

It is important to point out that the Brumadinho disaster is not an isolated event in Latin America. Other examples, just to cite a few, are the continuous oil spills in Ecuador (56–58), environmental impacts of transgenics in Argentina (59), and disasters caused by mining in Chile (60). Such events and how they are usually managed show that the assumption that there is a passive, sacrificial and appropriate nature promotes huge pressure and impact on people, animals and ecosystems - especially on those in situations of vulnerability and living in countries with high social inequality (61).

Besides, the assumption that nature is an object to be sacrificed for human interests and needs reinforce and reiterate asymmetries, producing *regimes of truth* **(Panel 1)** and invalidations, that is, relegates other perspectives to a status of mere beliefs or metaphors (42). However, such assumption is neither natural nor cosmopolitan: it comes across the borders of other worlds, such as the Indigenous ones, which refuse to obey the mandate of the nature/humanity division and resist the imposed extractive projects (44). The point is: the communicative exercise between worlds is important to make sure that no regime of truth is reproduced and no world is neglected in the process of decision making on health problems that concern multiple worlds.

Since One Health is proposed to be transdisciplinary and approach increasingly complex global health challenges, its practice and scientific production should not reproduce regimes of truth and invalidations. On the contrary, One Health should be open to the idea that the multiplicity of interactions among humans, animals and ecosystems can be formed by different assumptions, linked not to cultural differences, but ontological ones. Therefore, One Health professionals and researchers should be aware of - and closer to - discussions of alternative economic theories along with the perspectivism and the debate of multiple worlds - especially those that conduct research in Latin America, due to the ongoing impact of the extractivism previously discussed. Thus, people involved in One Health can facilitate and participate in transdisciplinary dialogues, overcoming the disciplinary barriers that divide the scientific practices in their countries.

CONCLUSION

Considering the challenging factors exemplified by the Brumadinho dam failure under the economics and anthropology lenses, we suggest that to achieve their goals, researchers and practitioners using One Health approaches should incorporate discussions of alternative economic theories and the multiple worlds perspective. This would help to reduce the limited dualistic and anthropocentric views and regimes of truth. Moreover, we argue that One Health should always be related to the context of the realities - plural - in which a particular problem, conflict or challenge is inserted. This implies that One Health should be plural or have several versions.

Based on the discussion of extractivism, transdisciplinarity and contributions of the social sciences, we suggest that in Brazil - and other Latin American countries with a similar context - it is fundamental and urgent to overcome disciplinary barriers in One Health. That is, it is essential to include the social sciences and their professionals in One Health debates, for an effectively transdisciplinary dialogue about the multiple and distinct interconnections among humans, animals and ecosystems.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

AUTHOR CONTRIBUTIONS

AB and AA conceptualized the paper. AB and SS contributed to One Health and transdisciplinarity discussions. JG and AA contributed to the Economics discussions. AA and DE contributed to the Anthropology discussions. All authors contributed to the writing of the manuscript, read, edited, and approved the final manuscript.

FUNDING

Publication fee for this article was granted by a scholarship received from an anonymous donor of One Health Brasil.

ACKNOWLEDGMENTS

We would like to thank all the colleagues working in the transdisciplinary team of the Portal Saúde Única (freely translated as One Health Portal); which is a platform dedicated to disseminate, popularize, and promote the One Health concept in Brazil through the creation of digital content.

REFERENCES

1. Lerner H, Berg C. A Comparison of three holistic approaches to health: one health, ecohealth, and planetary health. *Front vet sci.* (2017) 4:163. doi: 10.3389/fvets.2017.00163
2. Evans BR, Leighton FA. A history of one health. *Rev Sci Tech.* (2014) 33:413–20. doi: 10.20506/rst.33.2.2298
3. Machalaba CC, Daszak P, Karesh WB, Shrivastava P. Future earth and ecohealth: a new paradigm toward global sustainability and health. *Ecohealth.* (2015) 12:553–4. doi: 10.1007/s10393-015-1076-6
4. Whitmee S, Haines A, Beyrer C, Boltz F, Capon AG, de Souza Dias BF, et al. Safeguarding human health in the Anthropocene epoch: report of the rockefeller foundation-lancet commission on planetary health. *Lancet.* (2015) 386:1973–2028. doi: 10.1016/S0140-6736(15)60901-1
5. Buse CG, Oestreicher JS, Ellis NR, Patrick R, Brisbois B, Jenkins AP, et al. Public health guide to field developments linking ecosystems, environments and health in the Anthropocene. *J Epidemiol Community Health.* (2018) 72:420–5. doi: 10.1136/jech-2017-210082
6. Harrison S, Kivuti-Bitok L, Macmillan A, Priest P. Ecohealth and one health: a theory-focused review in response to calls for convergence. *Environ Int.* (2019) 132:105058. doi: 10.1016/j.envint.2019.105058
7. Rüegg SR, Buttigieg SC, Goutard FL, Binot A, Morand S, Thys S, et al. Concepts and experiences in framing, integration and evaluation of one health and ecohealth. *Front vet sci.* (2019) 6:155. doi: 10.3389/fvets.2019.00155
8. Lewis SL, Maslin MA. Defining the Anthropocene. *Nature.* (2015) 519:171–80. doi: 10.1038/nature14258
9. Brisbois BW. Mapping research on resource extraction and health: a scoping review. *Extr Ind Soc.* (2019) 6:250–9. doi: 10.1016/j.exis.2018.10.017
10. Moysés SJ, Soares RC. Planetary health in the Anthropocene. *Health Promot Int.* (2019) 34:i28–36. doi: 10.1093/heapro/daz012
11. Zinsstag J, Schelling E, Waltner-Toews D, Tanner M. From one medicine to one health and systemic approaches to health and well-being. *Prev Vet Med.* (2011) 101:148–56. doi: 10.1016/j.prevetmed.2010.07.003
12. Craddock S, Hinchliffe S. One world, one health? social science engagements with the one health agenda. *Soc Sci Med.* (2014) 129:1–4. doi: 10.1016/j.socscimed.2014.11.016
13. Lapinski MK, Funk JA, Moccia LT. Recommendations for the role of social science research in one health. *Soc Sci Med.* (2015) 129:51–60. doi: 10.1016/j.socscimed.2014.09.048
14. Michalon, J. Accounting for one health: insights from the social sciences. *Parasite*. (2020) 27:56. doi: 10.1051/parasite/2020056
15. One Health Commission. *Apex: One Health Comission c2021. One Health Social Sciences Initiative (2021)*. Available online at: https://www.onehealthcommission.org/en/programs/one_health_social_sciences_initiative/ (Accessed Jan 4, 2021).
16. Darlington S, Glanz J, Andreoni M, Bloch M, Peçanha S, Singhvi A, et al. *The New York Times:World.* (2019). Available online at: https://www.nytimes.com/interactive/2019/02/09/world/americas/brazil-dam-collapse.html (Accessed Jan 4, 2021).
17. Brasil. *Câmara dos Deputados. Comissão Parlamentar de Inquérito (CPI). Relatório: Rompimento da Barragem de Brumadinho [Report: Brumadinho Dam rupture]*. Brasília (2019). p. 2287*Portuguese*.
18. Silva AA, Lunas DAL, Bicalho PSS, Maciel RMT. The impact of the Brumadinho dam rupture in Naô Xohâ village = O impacto do rompimento da barragem de Brumadinho na aldeia Naô Xohã. *Sustentabilidade em Debate*. (2019) 10:195–211. doi: 10.18472/SustDeb.v10n3.2019.24017
19. *Vale: Brazil site S.A*. Available online at: http://www.vale.com/brasil/EN/aboutvale/reports/atualizacoes_brumadinho/Pages/updated-lists.aspx (Accessed Jan 4, 2021).
20. Polignano MV, Lemos RS. Rompimento da barragem da Vale em Brumadinho: impactos socioambientais na Bacia do Rio Paraopeba. *Ciência e Cultura*. (2020) 72:37–43. Portuguese. doi: 10.21800/2317-66602020000200011
21. Rotta LHS, Alcântara E, Park E, Negri RG, Lin YN, Bernardo N et al. The 2019 brumadinho tailings dam collapse: possible cause and impacts of the worst human and environmental disaster in Brazil. *Int J Appl Earth Obs Geoinf.* (2020) 90:102119. doi: 10.1016/j.jag.2020.102119
22. Prazeres L. *Vale é uma jóia e não pode ser condenada por Brumadinho, diz CEO da empresa. UOL:Cotidiano.* (2019). Available online at: https://noticias.uol.com.br/cotidiano/ultimas-noticias/2019/02/14/vale-e-joia-nao-pode-ser-condenada-por-brumadinho-diz-presidente-da-empresa.htm (Accessed Jan 4, 2021).
23. Pinheiro M. *Cortaram um pedaço do nosso corpo, diz cacique sobre Rio Paraopeba. Metrópoles:Brasil.* (2019). Available online at: https://www.metropoles.com/brasil/cortaram-um-pedaco-do-nosso-corpo-diz-cacique-sobre-rio-paraopeba (Accessed Jan 4, 2021).
24. Vasconcellos MAS. *Economia: Micro e Macro. São Paulo: Ed. Atlas.* (2011). p. 453.
25. Cavalcanti C. Conceptions of ecological economics: its relationship with mainstream and environmental economics = Concepções da economia ecológica: suas relações com a economia dominante e a economia ambiental. *Estudos avançados*. (2010) 24:53–67. doi: 10.1590/S0103-40142010000100007
26. Herrero Y. Miradas ecofeministas para transitar a un mundo justo y sostenible. *Revista de Economía Crítica*. (2013) 16:278–307.
27. Hunt EK, Lautzenheiser M. *História do pensamento econômico: uma perspectiva crítica [History of Economic Thought: a critical perspective*]. 3rd ed. Villela AA, translator. Rio de Janeiro: Elsevier (2013). p. 504.
28. Porto MF, Martinez Alier J, Ecologia política, economia ecológica e saúde coletiva: interfaces para a sustentabilidade do desenvolvimento e para a promoção da saúde. [Political ecology, ecological economics, and public health: interfaces for the sustainability of development and health promotion]. *Cad Saúde Pública.* (2007) 23:S503–12. Portuguese. doi: 10.1590/S0102-311X2007001600011
29. Martínez Alier J. *O ecologismo dos pobres: conflitos ambientais e linguagens de valoração [Conflictos ambientales y lenguajes de valoración*]. 2nd ed. Waldman M, translator. São Paulo: Contexto (2014). Portuguese.
30. Azam G. In: Solón, P. *Alternativas sistêmicas: Bem viver, decrescimento, comuns, ecofeminismo, direitos da mãe terra e desglobalização. São Paulo: Editora Elefante.* (2019). Chapter 2, Decrescimento. p. 65-84. Portuguese.
31. Latouche S. *Pequeno tratado do decrescimento sereno*. 1st ed. São Paulo: WMF Martins Fontes (2009). p. 170. Portuguese.
32. Gudynas E, Acosta A. La renovación de la crítica al desarrollo y el buen vivir como alternativa. *Utopía y praxis latinoamericana*. (2011) 16:71–83. Spanish. Available online at: https://www.redalyc.org/articulo.oa?id=27919220007
33. Acosta A. *O bem viver: uma oportunidade para imaginar outros mundos*. São Paulo: Autonomia Literária. Editora Elefante (2019). p. 264. Portuguese.

34. Chuji M, Rengifo G, Gudynas E. Buen vivir. In: Kothari A, Salleh A, Escobar A, Demaria F, Acosta A. *Pluriverse - A Post-Development Dictionary*. New Delhi: Tulika Books. Authors Upfront (2019). p. 111–4.
35. Escobar A. Territorios de diferencia: la ontología política de los derechos al territorio [territories of difference: political ontology of the rights to territory]. *Cuadernos de Antropología Social*. (2015) (41):25–38. doi: 10.5380/dma.v35i0.43540
36. Viveiros de Castro E. Os pronomes cosmológicos e o perspectivismo ameríndio. *Mana*. (1996) 22:115–44. Portuguese. [English version: Viveiros de Castro E. Cosmological deixis and amerindian perspectivism. J Royal anthropol Inst. (1998) 4:469–88]. doi: 10.1590/S0104-93131996000200005
37. Calavia Sáez O. Do perspectivismo ameríndio ao índio real [from amerindian perspectivism to the real indian]. *Campos*. (2012) 13:7–23. doi: 10.5380/cam.v13i2.36728
38. Vanzolini M, Cesarino P. Perspectivism. In *obo in Anthropology*. Oxford University Press (2014). doi: 10.1093/obo/9780199766567-0083
39. Holbraad M, Pedersen MA. Natural relativism: Viveiros de Castro's perspectivism and multinaturalism. In: *The Ontological Turn: An Anthropological Exposition*. Cambridge: Cambridge University Press (2017). p. 157–98. doi: 10.1017/9781316218907
40. Viveiros de Castro E. *Metafísicas canibais: elementos para uma antropologia pós-estrutural. [Métaphysiques cannibales: lignes d'anthropologie post-structurale*]. 1ª ed. São Paulo: Cosac Naify (2015). Portuguese.
41. Viveiros de Castro E. *A inconstância da Alma Selvagem e outros ensaios*. São Paulo: Cosac Naify (2002). p. 552. Portuguese.
42. Blaser M. *Storytelling Globalization from the Chaco and Beyond*. Durham and London: Duke University Press (2010). P. 292. doi: 10.2307/j.ctv11cw0jf
43. Cadena M de la. Natureza incomum: histórias do antropo-cego = Uncommoning nature: stories from the Anthropo-not-seen. *Revista do Instituto de Estudos Brasileiros*. (2018) (69):95–117. doi: 10.11606/issn.2316-901X.v0i69p95-117
44. de la Cadena M. Protestando desde lo incomún. In: Santisteban RS, editor. *Mujeres indígenas frente al cambio climático*. Peru: Grupo Internacional de Trabajo sobre Asuntos Indígenas (2019). p. 35–48.
45. Viveiros de. Castro E. Perspectival anthropology and the method of controlled equivocation Tipití. *J Soc Anthropol Lowland South America.* (2004) 2:3–22. Available online at: https://digitalcommons.trinity.edu/tipiti/vol2/iss1/1/
46. Cadena M de la. Política indígena: un análisis más allá de la política. *Red de antropologías del Mundo (RAM).* (2008) 139–42. Available online at: http://ram-wan.net/old/documents/05_e_Journal/journal-4/jwan4.pdf
47. Iribarry IN. Aproximações sobre a transdisciplinaridade: algumas linhas históricas, fundamentos e princípios aplicados ao trabalho de equipe [approaching transdisciplinarity: some historical lines, foundations and applied principles to team work]. *Psicologia: reflexão e crítica*. (2003) 16:483–90. doi: 10.1590/S0102-79722003000300007
48. Almeida Filho ND. Transdisciplinaridade e o paradigma pós-disciplinar na saúde [transdisciplinarity and the post-disciplinary paradigm in health]. *Saúde e Sociedade*. (2005) 14:30–50. doi: 10.1590/S0104-12902005000300004
49. Nicolescu B. Transdisciplinarity: past, present and future. In: Haverkort B, Reijntjes C. *Moving Worldviews: Reshaping Sciences, Policies And Practices For Endogenous Sustainable Development. Compas series on worldviews and sciences 4.* Leusden: ETC/COMPAS. 2007. p. 142–66.
50. Nicolescu B. *O Manifesto da Transdisciplinaridade [Manifesto Of Transdisciplinarity*]. 3rd ed. Souza, LP, translator. São Paulo: Triom (2005). Portuguese.
51. Paim JS, Travassos CMR, Almeida CM, Bahia L, Macinko J. The Brazilian health system: history, advances, and challenges = O sistema de saúde brasileiro: história, avanços e desafios. *Lancet.* (2011) 377:1778–97. doi: 10.1016/S0140-6736(11)60054-8
52. Nunes ED. Saúde coletiva: história de uma ideia e de um conceito. *Saúde e sociedade.* (1994) 3:5–21. doi: 10.1590/S0104-129019940002 00002
53. Harris M, Haines A. Brazil's family health programme. *BMJ.* (2010) 341:c4945. doi: 10.1136/bmj.c4945
54. Feriotti ML. Equipe multiprofissional, transdisciplinaridade e saúde: desafios do nosso tempo. *Vínculo-Revista do NESME.* (2009) 6:179–93. Available online at: https://www.redalyc.org/articulo.oa?id=139422410007
55. Fonseca LEG. A transdisciplinaridade na educação superior. *Outras palavras.* (2016) 12. Portuguese. Available online at: http://revista.faculdadeprojecao.edu.br/index.php/Projecao5/article/view/670
56. Azevedo-Santos VM, Garcia-Ayala JR, Fearnside PM, Esteves FA, Pelicice FM, Laurance WF, et al. Amazon aquatic biodiversity imperiled by oil spills. *Biodivers Conserv*. (2016) 25:2831–4. doi: 10.1007/s10531-016-1 192-9
57. Maurice L, López F, Becerra S, Jamhoury H, Le Menach K, Dévier MH et al. Drinking water quality in areas impacted by oil activities in Ecuador: Associated health risks and social perception of human exposure. *Science of The Total Environment.* (2019) 690:1203–17. doi: 10.1016/j.scitotenv.2019.07.089
58. Rivera-Parra JL, Vizcarra C, Mora K, Mayorga H, Dueñas JC. Spatial distribution of oil spills in the north eastern Ecuadorian Amazon: A comprehensive review of possible threats. *Biol Conserv.* (2020) 252:108820. doi: 10.1016/j.biocon.2020.108820
59. Lapegna P, Otero G. Cultivos transgénicos en América Latina: expropiación, valor negativo y Estado. Estudios Críticos del Desarrollo. 2016; 6(11):19–43. Spanish. doi: 10.35533/ecd.0611.pl.go
60. Compagnoni UM, Silva JC, Harzer JH. A complexidade e a gestão estratégica do resgate dos 33 mineiros soterrados na mina San Jose no Chile. Simpoi, anais. 2011. Portuguese.
61. Dias AO; Luz GS, Assunção VK, Gonçalves, TM. In: Ladwig NI, Schwalm H. Planejamento e gestão territorial: a sustentabilidade dos ecossistemas urbanos. Criciúma: EDIUNESC. 2018. Chapter 20: Mariana, o maior desastre ambiental do Brasil: uma análise do conflito socioambiental. p. 455–76. Portuguese. doi: 10.18616/pgt20
62. Blaser M, Cadena M de la. *A World Of Many Worlds*. Durham: Duke University Press (2018). *Introduction: Pluriverse: Proposals For A World Of Many Worlds*. p. 1–22. doi: 10.2307/j.ctv125jpzq.4
63. Foucault M. The Political Function of the Intellectual. *Radical Philosophy.* (1977) 17:12–4.

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

PANEL 1. GLOSSARY

Anthropocene: It is an expression that designates a new era, subsequent to the Holocene, in which humanity has become a global geological force capable of changing the existence of systems and life forms on Earth (8).

Challenging factors: Important elements evidenced by the social sciences that, in a transdisciplinary context, increase the awareness of complexity of health topics. Such elements challenge the way health has been traditionally understood and practiced in the modern world. Challenging factors can be, for example: ontological differences; gender, racial or ethnic inequalities; religious or regional aspects (our definition).

Equivocation: Concept introduced by the anthropologist Eduardo Viveiros de Castro - in the Perspectivism theory - that seeks to explain the mode of communication between Amerindian inhabitants (human and non-human) in the Brazilian Amazon. The term refers to the "referential alterity between homonymic concepts", or the "mode of communication par excellence between different perspectival positions" (43, 45). See more in section Anthropology: When Assumptions are not Common - or the Same - Among Worlds of this current article.

Externality: Benefits or costs arising from the production or consumption process that are not considered in the economic model (24).

Multiple worlds (pluriverse): Discussion that confronts the idea of modernity that there is only one world, proposing "a world of many worlds" or a world in which many different worlds can fit, such as the Indigenous and non-Indigenous worlds (62). See more in section Anthropology: When Assumptions are not Common - or the Same - Among Worlds of this current article.

One Health: A concept that acknowledge that the health of humans, animals, plants and ecosystems are deeply connected and therefore must be thought and worked together. For this, it is suggested the use of transdisciplinary and multisectoral health strategies and approaches (our definition).

Ontology: We use "ontology" as defined by Mario Blaser (2010) in three distinct – but not excluding – layers of meaning: 1. From sociology - "kinds of being and their relations"; 2. From science and technology - "ontologies are shaped through the practices and interactions of both human and non-humans;" and 3. From his ethnographic work - "ontologies manifest as "stories" in which the assumptions of what kinds of things and relations make up a given world are readily graspable" (42).

Regimes of Truth: Concept introduced by Michel Foucault in 1975 defined as the "types of discourse it [society] harbours and causes to function as true; the mechanisms and instances which enable one to distinguish true from false statements, the way in which each is sanctioned; the techniques and procedures which are valorised for obtaining truth; the status of those who are charged with saying what counts as true" (63).

Transdisciplinarity: as the prefix "trans" indicates, it concerns what is - at the same time - *between* disciplines, *trough* the different disciplines and *beyond* any discipline. The aim of transdisciplinarity is the understanding of the present world(s), for which one of the imperatives is the unity of knowledge (50).

frontiers in Public Health

BRIEF RESEARCH REPORT
published: 21 October 2021
doi: 10.3389/fpubh.2021.647903

Canine Olfactory Detection of SARS-COV2-Infected Patients: A One Health Approach

Rita de Cássia Carvalho Maia [1*†], Leucio Câmara Alves [1†], Jeine Emanuele Santos da Silva [2†], François Rémi Czyba [3†], Jorge Antonio Pereira [3†], Vincent Soistier [3†], Clothilde Lecoq Julien [4†], Dominique Grandjean [4†] and Anísio Francisco Soares [2†]

[1] Veterinary Medicine Department, Federal Rural University of Pernambuco, Recife, Brazil, [2] Animal Morphology and Physiology Department, Federal Rural University of Pernambuco, Recife, Brazil, [3] Amarante do Brasil, Avenida Erasmo Braga, Rio de Janeiro, Brazil, [4] National Veterinary School of Alfort, Maisons Alfort, France

The aim of the present study is to apply the canine olfactory sensitivity to detect COVID-19-positive axillary sweat samples as a One Health approach in Latin America. One hundred volunteers with COVID-like symptoms were invited to participate, and both axillary sweat samples for dog detection and nasopharynx/oropharynx swabs for qPCR were collected. Two dogs, previously trained, detected 97.4% of the samples positive for COVID-19, including a false-negative qPCR-test, and the positive predictive value was 100% and the negative predictive value was 98.2%. Therefore, we can conclude that canine olfactory sensitivity can detect a person infected with COVID-19 through axillary sweat successfully and could be used as an alternative to screen them without invasive testing.

Keywords: dog, COVID-19, odor, axillar, diagnosis, Latin America, one health

OPEN ACCESS

Edited by:
Laura H. Kahn,
Princeton University, United States

Reviewed by:
Nicolas Granger,
CVS Group Plc, United Kingdom
Corrie Cabell Brown,
University of Georgia, United States

***Correspondence:**
Rita de Cássia Carvalho Maia
rita.carvalho@ufrpe.br
orcid.org/0000-0001-6765-6686

† These authors have contributed equally to this work

Specialty section:
This article was submitted to Planetary Health, a section of the journal Frontiers in Public Health

Received: 30 December 2020
Accepted: 13 September 2021
Published: 21 October 2021

Citation:
Maia RCC, Alves LC, Silva JES, Czyba FR, Pereira JA, Soistier V, Julien CL, Grandjean D and Soares AF (2021) Canine Olfactory Detection of SARS-COV2-Infected Patients: A One Health Approach. Front. Public Health 9:647903. doi: 10.3389/fpubh.2021.647903

INTRODUCTION

Recent events during the SARS-CoV2 Pandemic development, initiated in the Wuhan Province in China in November 2019 (1), have brought enormous challenges to a population adapted to the globalized aspects of daily life, contributing largely to the continuity of the disease development, and augmenting the Public Health impact (2, 3). Letting go of these connections has been difficult. On the other hand, the reach of current technologies combined with mutual scientific collaboration worldwide has brought faster and more efficient responses to health problems when associated with a stronger and broader view of One Health, especially considering the involvement of animals at different levels of the epidemiologic chain of the disease (4). Among the problems envisioned, we observed the need to lower the costs of diagnostic tests, since the actual diagnostic performance depends on testing during different stages of the disease directly, depending on viral load, or indirectly at later stages, depending on antibody production. The reduction of testing also minimizes environmental impacts due to the large use of disposable materials, mainly plastic. Moreover, these tests bring a large margin of error due to the false-negative results given the failure to detect viral load or antibody production and thereby, adding the burden of asymptomatic patients being left untested (5), propagating the infection freely and risking further human, animal, and environmental dissemination. Another major obstacle is the cost of testing a large number of people (6) especially for those in developing countries. Above all remains the logistics of reopening and returning from quarantines that will resume physical contact, and the invasiveness of current tests that depend on tracheal or blood collections.

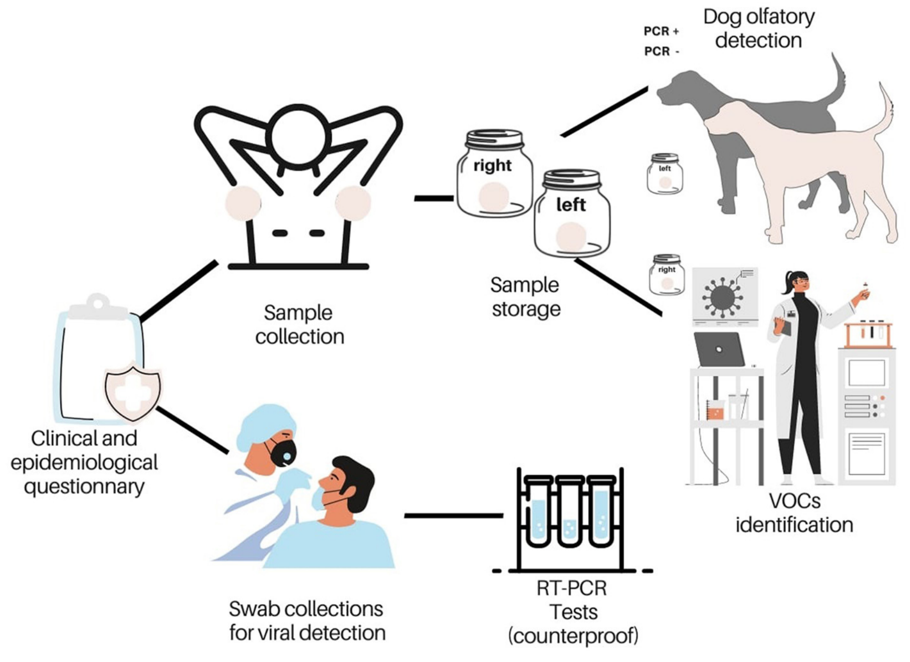

FIGURE 1 | Schematic representation depicting sample collection.

Using canine smell to locate buried people, drugs, and ammunition in different environments is a well-known, recognized, and applied activity (7, 8). The reason for this is confidence in the canine response to the most diverse volatile compounds emitted. Evaluating the problem in a broader One Health approach like using dogs to detect chronic degenerative and proliferative diseases by identifying Volatile Organic Compounds (VOCs) produced in the metabolism in the body of a patient during the disease has been a practice used for many diseases, such as several types of cancer, Parkinson's disease, and viral diseases, including coronavirus disease-2019 (COVID-19) (9–16). The olfactory detection capacity of the dog allies the large nasal cavity with an expressive olfactory epithelium surface area containing 30% more olfactory receptors than those in humans (17). Additionally, during the active sniffing process, characterized by short and sharp inhalations, the air inhaled into the nostrils is directed to the dorsal nasal cavity, flowing back to the ethmoturbinates. This process allows a longer exposure time of VOCs to the olfactory chemoreceptors, with a continuous stimulation of the olfactory centers throughout the respiratory cycle (18). Taken together, the advantages to humans, the environment, and animals in this context, the present project has as its main objective the application of a new approach for early detection of COVID-19 in humans through canine olfactory sensitivity to counteract the many challenges imposed by this disease.

MATERIALS AND METHODS

One hundred volunteers were selected to participate in the research. During a visit to patients with flu syndrome symptoms by the team of health agents from the Municipality of Paudalho, the northern region of Recife, Brazil, they were invited to participate in the research and signed the Free and Informed Consent Form. They were instructed to remain without bathing or using perfumes for the next 24 h, and sample collection was carried out the next day. Two types of samples were collected, one for the olfactory test of the dogs and another for confirming the patient diagnosis which was also used as a counterproof of the result achieved by the dogs. A questionnaire of clinical and epidemiological interest was also applied. The sample collection for dog training was performed by asking the volunteer to place a cotton ball under each armpit for 20 min (**Figure 1**). The cotton pads were collected and placed separately in hermetically sealed glass jars and labeled to precisely identify the origin of the sample. Sample collections for viral detection by RT-PCR were performed using a combination of two rayon swabs from the nasopharynx and oropharynx, stored in a 0.85% saline buffer per volunteer. The samples were collected by professionally trained health professionals at the Paudalho Municipal Laboratory following all Biosafety rules. After collection, the material was packed and stored in a cooled thermal box to avoid contamination of the samples during transportation. They were delivered for analysis within 2 h of collection.

The cotton balls samples were stored separately, one was used for the detection of odors by dogs, and the other was stored for further analysis. The samples were used 1 week after collection, to allow greater safety regarding infection of the trainer and the dogs to be trained. Dog training was performed at K9 International company which was largely experienced in dog training. Two healthy dogs, a male, and a female were used in this initial phase of the study. The dogs have been trained beforehand using

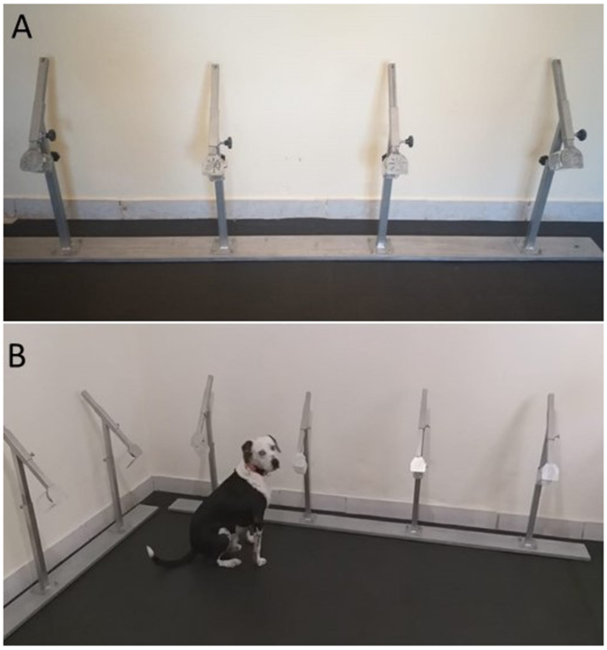

FIGURE 2 | The experiment of olfactory detection by dogs. **(A)** Testing line of samples. **(B)** Male dog, Sinatra, indicating the positive sample by sitting in front of the sample.

operant conditioning (reward-based training) on an 8-station scent line. The tests were double-blind and performed in an isolated room without external stimuli. During the tests, only the dog and trainer were present in the room. Two metallic bars with four holders each were used to hold the samples, keeping a 50 cm space between each holder (**Figure 2A**). The sample was placed in the container by the experimenter, where one known PCR-positive sample was placed in a random holder and the other seven holders were kept with clean cotton balls as negative samples. After training was established, PCR-negative samples were used instead of clean cotton balls as negative samples to avoid confusing the dogs with smells of PCR false-negative samples. Sequentially, the trainer stimulated the dog to sniff every pot in the row, and when the dog sat in front of a sample (**Figure 2B**), the experimenter, a person from outside the room and following the test, indicated whether the dog was correct, and the trainer would praise and award the dog. Neither the trainer or the dogs knew which were the positive samples nor where they were being placed, therefore assuring the double-blind test. The sessions were video recorded. Five positive samples were used (1 in each daily test session) and each dog made about five daily attempts (walking along the line of supports and smelling the samples). The positive samples were placed at different spots in the line and the trials were independent of each other to assure randomized locations. The sensitivity for dogs to detect COVID-19 was calculated as the proportion of the number of correct indications of positive samples by the dogs, considering their joint and individual performance.

RESULTS

The results obtained showed that among the population sample ($n = 100$), 63% of volunteers were female and 37% male. In the analysis of the samples using the RT-PCR technique, 44% of the individuals tested positive for COVID-19. The mean age was 36.0 $\pm$ 2.1 among the positives, while for the negative ones, values of 40.2 $\pm$ 2.3 were obtained. Regarding the average body mass, 73.8 $\pm$ 2.4 kg was observed among the positives and 74.6 $\pm$ 1.8 kg among the negatives for COVID-19.

Concerning pre-existing diseases or comorbidities, only 30% of individuals who tested positive for COVID-19 reported any changes. However, among these, hypertension was reported in approximately 85% of cases in isolation (61.5%), associated with asthma (7.7%), or diabetes (15.4%). When asked about the main associated symptoms, headaches, loss of smell, fever, dry cough, and body aches were reported.

Considering individuals that tested positive for COVID-19, 63 (6%) were women and 36 (4%) were men. When comparing casuistry related to ethnicity, it was found that among the positive cases, the proportion between whites, blacks, and browns was 18.2, 38.6, and 43.2%, respectively. Regarding the experiments carried out with dogs, they correctly indicated 97.4% of the samples were positive for COVID-19. As for individual performance, the male animal showed 100% sensitivity while the female showed 95% sensitivity for the tests performed. Interestingly, they also consistently indicated one of the PCR-negative samples as positive, therefore, we decided to contact the patient and performed a new serological test, that took place 45 days after the first collection, where antibodies against SARS-COV2 were observed, confirming a false-negative result in the PCR, which was correctly identified by the dogs. Our tests showed that the dogs could predict the subject truly having the disease since the positive predictive value (PPV) was 100%, and reversely, the negative predictive value (NPV) when considering the probability of the subject not having the disease was 98.2% in accuracy.

DISCUSSION

Considering that current testing methods to screen SARS-COV2 in the population are costly, invasive, and time-consuming, in addition to the need to return to activities after quarantine and due to the expected endemicity of the disease in the human population, it has been crucial to find fast and safe screening methods which preferably, would not require individual sample collection and will allow the screening of a large number of individuals. In the perspective of One Health, considering the acquired knowledge among human, animal, and environmental scientists brought together, using dogs to detect the odor of COVID-19-positive patients has been shown to work favorably in at least four countries, such as France, Lebanon, Colombia, and Germany (14–16). One Health means that a balance is required to maintain life on Earth. With that in mind, we further explore the advantages of developing and applying this approach to detect COVID-19 using dogs. It impacts positively on the reduction of plastic and use of disposable materials, minimizes the environmental spread of the virus from undetected patients, reduces the invasiveness of current tests, and promotes early detection of infection. Moreover, since animals are still understudies for correctly identifying their role in the epidemiologic chain, dogs may become a sentinel and valid option for surveillance in other animals. The present study showed that trained dogs can detect COVID-19-positive patients based on the odor they release. They were also able to detect a PCR false-negative patient, as proved by serological testing of that same patient 45 days later. Our study reached 97.4% of success when considering both dogs. Similarly, other studies showed between 81 and 100% correct answers (14–16).

Regarding the type of sample, two studies (15, 16) used saliva or tracheobronchial secretions. Regardless, the dogs were still able to detect the odor, reaching similar results, despite samples being different from ours as we used a much safer sampler than infected respiratory samples. Another study (14) used the same type of sample presented in this study (axillary sweat), worked with eight dogs, and notably obtained about 83–100% success, with all of them significantly different from the percentage of success expected by chance alone. Whether other illnesses were associated with those patients was not the focus of this study, but future studies may show whether there is a connection between different diseases and detection.

Compared with other studies, the present study used less invasive clinical samples and presented a lower risk of infection for humans and contamination to the surrounding environment than those using oral and respiratory secretion samples (15, 16). Although the influence of the prevalence of diseases in the success of the testing needs to be accessed on field trials, this approach suggests that the dogs, given the opportunity, can access and screen patients without the hassle of taking any sample to a laboratory.

Considering the major disturbance caused by COVID-19 in everyday life, especially the necessity of returning the mobility of the population to a more regular level, the use of canine olfactive detection to identify COVID-19-positive individuals, a non-invasive technique using axillary sweat sample, has shown to become a very promising avenue. In this study, we have shown an above 97% success in identifying COVID-19-positive samples, including a false-negative RT-PCR sample by dog olfactive detection, with PPV of 100% and NPV above 98%. Taken together, these results and the statistics associated with them are extremely important to corroborate this successful One Health approach in Latin America as a means to reduce human, environmental, and animal risk of exposure to COVID-19.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethics Commitee of UFRPE: CEP UFRPE no. 4.112.622. The patients/participants provided their written informed consent to participate in this study. The animal study was reviewed and approved by Ethics Committee from UFRPE: CEUA UFRPE no. 6804230520.

AUTHOR CONTRIBUTIONS

AS, RM, LA, JS, FC, JP, VS, DG, and CJ in order to accomplish this work, from the intellectual process, every step involved in planning, designing the protocols, and analyzing the results and writing the article. All authors contributed to the article and approved the submitted version.

ACKNOWLEDGMENTS

To those who make the Health Department of the municipality of Paudalho/PE, for the dedication and contributions that were essential to the development of this work, and especially, to all volunteers who use SUS, without whom it would not have been possible.

REFERENCES

1. Roujian Lu XZ, Li JP, Niu P, Yang B, Wu H, Wang W, et al. Genomic characterisation and epidemiology of 2019 novel coronavirus: implications for virus origins and receptor binding. *Lancet*. (2020) 395:565–74. doi: 10.1016/S0140-6736(20)30251-8
2. Editorial Comment. COVID19 and Globalization. *One Health*. (2020) 9:100132. doi: 10.1016/j.onehlt.2020.100132
3. Sun J, He WT, Wang L, Lai A, Ji X, Zhai X, et al. COVID19: epidemiology, evolution, cross-disciplinary perspectives. *Trends Mol Med.* (2020) 26:483–95. doi: 10.1016/j.molmed.2020.02.008
4. Leroy EM, Gouilhb AR, Brugere-Picouxc J. The risk of SARS-CoV-2 transmission to pets and other wild and domestic animals strongly mandates a one-health strategy to control the COVID19 pandemic. *One Health*. (2020) 10:100133. doi: 10.1016/j.onehlt.2020.100133
5. Bai Y, Yao L, Wei T, Tian F, Jin DY, Chen L, et al. Presumed asymptomatic carrier transmission of COVID19. *JAMA*. (2020) 323:1406–7. doi: 10.1001/jama.2020.2565
6. Goodell JW. COVID19 and finance: agendas for future research. *Fin Res Lett.* (2020) 35:101512. doi: 10.1016/j.frl.2020.101512
7. Browne C, Stafford K, Fordham R. The use of scent-detection dogs. *Irish Vet J.* (2006) 59:97.
8. Statheropoulos M, Mikedi K, Agapiou A, Georgiadou A, Karma S. Discriminant analysis of volatile organic compounds data related to a new location method of entrapped people in collapsed buildings of an earthquake. *Anal Chim Acta.* (2006) 566:207–16. doi: 10.1016/j.aca.2006.03.023
9. Rudnicka J, Walczak M, Kowalkowski T, Jezierski T, Buszewski B. Determination of volatile organic compounds as potential markers of lung cancer by gas chromatography–mass spectrometry versus trained dogs. *Sens Actuat B Chem.* (2014) 202:615–21. doi: 10.1016/j.snb.2014.06.006
10. Cornu JN, Cancel-Tassin G, Ondet V, Girardet C, Cussenot O. Olfactory detection of prostate cancer by dogs sniffing urine: a step forward in early diagnosis. *Euro Urol.* (2011) 59:197–201. doi: 10.1016/j.eururo.2010.10.006
11. Willis CM, Britton LE, Harris R, Wallace J, Guest CM. Volatile organic compounds as biomarkers of bladder cancer: sensitivity and specificity using trained sniffer dogs. *Cancer Biomark.* (2011) 8:145–53. doi: 10.3233/CBM-2011-0208

12. Angle C, Waggoner LP, Ferrando A, Haney P, Passler T. Canine detection of the volatilome: a review of implications for pathogen and disease detection. *Front Vet Sci.* (2016) 3:47. doi: 10.3389/fvets.2016.00047
13. Angle TC, Passler T, Waggoner PL, Fischer TD, Rogers B, Galik PK, et al. Real-time detection of a virus using detection dogs. *Front Vet Sci.* (2016) 2:79. doi: 10.3389/fvets.2015.00079
14. Grandjean D, Sarkis R, Tourtier JP, Julien C, Desquilbet L. Detection dogs as a help in the detection of COVID19: can the dog alert on COVID19 positive persons by sniffing axillary sweat samples? Proof-of-concept study. *PLoS ONE*. (2020) 15:e0243122. doi: 10.1371/journal.pone.0243122
15. Vesga O, Valencia AF, Mira A, Ossa F, Ocampo E, Perez MA, et al. Dog savior: immediate scent-detection of SARS-COV-2 by trained dogs. *bioRxiv*. (2020). doi: 10.1101/2020.06.17.158105
16. Jendrny P, Schulz C, Twele F, Meller S, von Köckritz-Blickwede M, Osterhaus, et al. Scent dog identification of samples from COVID19 patients–a pilot study. *BMC Infect Dis.* (2020) 20:1–7. doi: 10.1186/s12879-020-05281-3
17. Barrios AW, Sánchez-Quinteiro P, Salazar I. Dog and mouse: toward a balanced view of the mammalian olfactory system. *Front Neuroanat.* (2014) 8:106. doi: 10.3389/fnana.2014.00106
18. Craven BA, Paterson EG, Settles GS. The fluid dynamics of canine olfaction: unique nasal airflow patterns as an explanation of macrosmia. *J R Soc Interface.* (2010) 7:933–43. doi: 10.1098/rsif.2009.0490

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

frontiers in Public Health

ORIGINAL RESEARCH
published: 25 October 2021
doi: 10.3389/fpubh.2021.649240

A Survey on One Health Approach in Colombia and Some Latin American Countries: From a Fragmented Health Organization to an Integrated Health Response to Global Challenges

Natalia Margarita Cediel Becerra[1†], Ana María Olaya Medellin[2†], Laura Tomassone[3], Francesco Chiesa[3] and Daniele De Meneghi[3]*

[1] Epidemiology and Public Health Research Group, Veterinary Medicine Program, School of Agricultural Sciences, Universidad de La Salle, Bogotá, Colombia, [2] Veterinary Medicine Program, School of Agricultural Sciences, Universidad de La Salle, Bogotá, Colombia, [3] Department of Veterinary Science, University of Turin, Grugliasco-Turin, Italy

OPEN ACCESS

Edited by:
Christina Pettan-Brewer, University of Washington, United States

Reviewed by:
Simon Rodrigo Rüegg, University of Zurich, Switzerland
Lisa Cavalerie, University of Liverpool, United Kingdom

***Correspondence:**
Natalia Margarita Cediel Becerra
nmcedielb@unisalle.edu.co

† These authors have contributed equally to this work

Specialty section:
This article was submitted to Planetary Health, a section of the journal Frontiers in Public Health

***Received:** 04 January 2021*
***Accepted:** 23 September 2021*
***Published:** 25 October 2021*

Citation:
Cediel Becerra NM, Olaya Medellin AM, Tomassone L, Chiesa F and De Meneghi D (2021) A Survey on One Health Approach in Colombia and Some Latin American Countries: From a Fragmented Health Organization to an Integrated Health Response to Global Challenges. Front. Public Health 9:649240. doi: 10.3389/fpubh.2021.649240

The "One Health" (OH) approach has been recognized by world health authorities such as FAO/OIE/WHO, advocating for effective, multi-sectoral, and transdisciplinary collaboration. However, there is a lack of published evidence of the awareness of the OH concept in Colombia and other countries in the Latin American Region. In order to explore existing collaboration amongst the animal health, human-public health, environmental health sectors, and to describe the perception, knowledge, and barriers on OH in Colombia and other countries of Latin America, an online questionnaire-based survey was distributed among key professionals representing the three OH pillars (August 2018–August 2020). Overall, 76 key respondents from 13 countries (Colombia, México, Chile, Brazil, Argentina, Bolivia, Costa Rica, Ecuador, Perú, Guatemala, Nicaragua Uruguay, and Venezuela) completed the questionnaire. Respondents worked in institutions of animal (59%), public (20%), human (7%), and environmental health (7%); they mainly belonged to higher academic institutions (59%), followed by ministries (11%), and research organizations (9%). Most participants (92%) were familiar with the OH term and 68% were aware of the formal cooperation among sectors in their countries, mostly on zoonoses; in 46% of the cases, such connections were established in the last 5 years. The main reported limiting factors to intersectorality were the lack of commitment of policy-makers, resources, and budget for OH (38%) and the "siloed approach" of sectors and disciplines (34%). Respondents ranked a median score of 3.0 (1–5 scoring) in how good OH activities are implemented in their countries, and a median score of 2.0 in the citizen awareness on OH as regards their countries. The most important OH issues were identified in vector-borne diseases, rabies, wrong and/or improper use of antimicrobials, emerging viral diseases, food-borne diseases, neglected parasitic diseases, deforestation, and ecosystem fragmentation. Although there is a high-perceived importance on conjoint cooperation, OH implementation, and operationalization remain weak, and the environmental component is not well-integrated. We consider that integration and implementation of the OH Approach can support countries to improve their health policies and health governance as well as to advocate the social, economic, and environmental sustainability of the Region.

Keywords: intersectoral collaboration, Latin America countries, one health, questionnaire survey, perception, barriers, Colombia

INTRODUCTION

During the last 15 years, there has been an increased focus on the human-animal-ecosystem interface. Pathogens continue to evolve and adapt to new hosts and environments, threatening human and animal health systems. Highly pathogenic avian influenza and some other infectious diseases, COVID-19 as latest example, have created an opportunity toward a One Health (OH) approach that incorporates a collaborative, cross-sectoral, multidisciplinary mode of addressing these threats, and reducing health risks (1). Consequently, OH underwent a revival from the academy, the government, and international organizations (2).

One Health has been defined by the WHO as "an approach to designing and implementing programs, policies, legislation, and research in which multiple sectors communicate and work together to achieve better public health outcomes" (3). This definition confirms the importance of the animal-human-environment interface and how vital it is to ensure the adoption of a OH approach in public health legislation in all countries. The roots of this paradigm lie in the fertile grounds of comparative pathology, driven by the remarkable efforts, perspectives, and writings of William Osler, Calvin Schwabe, Rudolf Virchow, and many others (4). The OH approach, therefore, involves combined assessment of health risks across the three domains of humans, animals, and the environment, and it involves design and implementation of intervention and prevention strategies that address all three sectors with the goal of producing integrated knowledge (5). The OH collaboration has the potential to benefit many sectors, having among its advantages: more efficient and effective surveillance programs, better development of laboratory capacity, improved targeting efficient outbreak prediction, implementation of common disease control strategies, identifying integrated research activities across sectors (human, animal, environmental) (6).

Despite an intuitive appreciation that complex health problems need to be tackled through an integration of the interdisciplinary and transdisciplinary approaches that define OH, there is still need to generate quantitative and qualitative evidence to clearly demonstrate these benefits and its added value (7, 8). Collaborative approaches in health are promising; nevertheless, several authors point at persistent challenges for designing and implementing OH initiatives. The degree and quality of collaboration amongst various health disciplines and institutions varies substantially (9). Integrated approaches to health are challenging because they require complex systems of communication and collaboration that are difficult to delimit (9). Rüegg et al. (9), reflecting on the concrete challenges for OH implementation, described real case studies of application of OH in different countries. The most important topics to consider were related to the social dimensions and power dynamics among professional participants that affect OH implementation, the importance of local and national levels for the successful realization of OH, how the social-ecological systems and resilience theory contribute to the OH approach. However, the national borders are challenging for the sharing of epidemiologic data and systems thinking is challenging for many natural scientists (10).

In Latin America, a One Health International Network (OHLAIC) was started as an international cooperation initiative with representatives and leaders from over 20 countries. It was created in December 2017 through virtual communications between the One Health Commission (OHC), OH Platform (in connection of OH Day) and five OH representatives from Chile, Brazil, Perú, and Colombia as the co-founders. This OHLAIC Network met in person with further OH experts of representative countries in Monteria, Colombia in 2018 and 2019 (11, 12). This network goal is addressing urgent health problems in Latin America without any competitiveness between areas (https://ohlaic.org/es/) and representing English, Spanish, French, and Portuguese speaking countries. Specifically, in Colombia, the OH concept has been deepened by the Academia since the creation of SPVet network, created following a recommendation made at the First Meeting of Veterinary Public Health, held in Bogotá in 2003, under the auspices of the Representation of PAHO/WHO. During this meeting, an important dialogue was carried out related to food hygiene, prevention of zoonoses, weak public perception of the role of veterinarians in the health of society, low importance of veterinary public health in higher education, and limitation of guidelines for professional practices and the consequent fragmentation of the agricultural sector in the decision-making regarding the health system and the development of the country. The objectives of the SPVet network were: maintaining a continuous and timely flow of information on veterinary public health topics, strengthening ties of cooperation and support among specialists, create a space for discussion and consultation on topics of national interest as international, and contribute to the strengthening of undergraduate and graduate academic activities in veterinary public health with the participation in the Sapuvetnet project, an international network aimed to promote and harmonize teaching and research on Veterinary Public Health across Latin America and Europe. This international project contributed to develop and share innovative undergraduate teaching material on the importance of intersectoral collaboration and multidisciplinary cooperation to face the most important global challenges (13, 14).

There are an increasing number of researchers from universities and government agencies across many countries of the Latin American region, with different expertise and disciplinary backgrounds that may facilitate a more comprehensive perspective at the human-animal-environment interface. However, there is a gap in knowledge on the state of OH approach in Latin American countries it seems there is a lack of direction on the implementation of OH initiatives among stakeholders, despite the World Bank published guidance on how to operationalize OH (15).

In order to explore existing collaboration amongst the animal health, human-public health and environmental health sectors, and to describe the perception and knowledge on OH in Colombia and other countries in Latin America, a questionnaire-based survey was circulated amongst main stakeholders.

MATERIALS AND METHODS

Our questionnaire was derived from a similar questionnaire used to carry out a qualitative survey on OH perception and experiences in Europe and neighboring areas (16). The questionnaire aimed to assess the perception and experiences from key stakeholders on OH. This form was developed in Google Forms (https://docs.google.com/forms/) and distributed by email within the networks to which one of the authors belongs (NC): Sapuvet and the "One Health Latin American and Iberoamerica and the Caribbean network" (OHLAIC). The potential participants were reminded about compiling the questionnaire every 3 months via mail. Likewise, a personal invitation to participate in the study was sent to the major representatives of public health authorities and animal health authorities in Colombia, Mexico, and Perú through the snowball sampling technique (17). This is a recruitment technique in which research participants are asked to assist researchers in identifying other potential subjects. Likewise, several attempts were made to contact and invite the OIE Latin America and PAHO/WHO representatives to join the study.

The survey was organized in six sections: 1. *general information*; 2. *about "One Health"*; 3. *zoonotic diseases, environmental health and AMR: examples of "burning" OH issues/initiatives*; 4. *aspects limiting interdisciplinarity and intersectionality in OH*; 5. *conclusions*; 6. *end of questionnaire* (including comments, remarks and/or suggestions). The survey consisted of 27 questions, 21 closed-ended questions and 6 open-ended questions. An informed consent form was shown at the beginning of the questionnaire to warn the participants that the questionnaire was anonymous and that, by completing and submitting it, they voluntarily agreed to participate. In this way, an implicit confidentiality agreement was made with participants. Correspondingly, as our questionnaire is the same used in the survey on OH perception and experiences in Europe and neighboring areas (16), the ethical approval was granted by the Clinical Research and Ethical Review Board at the Royal Veterinary College, grant holder of COST Action TD1404 NEOH (ref. prot. n. URN 2016 1554).

The corresponding author contacted institutions and key actors and networks involved in OH in Latin America countries. Key respondents were meant to represent the three components of OH (animal, human/public, and environmental health) in each of the 21 countries, belonging to different institutions. Public institutions/ministries were represented by respondents working in the agricultural or health Ministry, veterinary services, or environmental services. We understand public health as the science of protecting and improving the health of people and their communities; public health professionals worked in areas related to the Ministry of Health (MoH), independently their college degree. Human health was defined by a state of complete physical, psychological, and social well-being; professionals working in these areas were physicians (medical doctors). Academia/research personnel (i.e., professors and researchers of the universities and national research centers), representatives of the private sector (i.e., members of the national boards/colleges of veterinarians, advisers, people belonging to the economic field selling goods or veterinary products, etc.), NGOs, associations, and scientific societies involved in OH initiatives and activities were also asked to answer the survey.

The targeted number of respondents was at least 126 (six respondents representing human, animal, and environmental health, two respondents of each component from the 21 countries of Latin America where the survey was sent). The questionnaire was accessible for 24 months (August 2018–August 2020). After the questionnaire was closed, the data collected were downloaded. Answers were checked for consistency, cleaned, and coded for analysis.

In section 3 of the questionnaire, participants were asked to select zoonotic diseases that are controlled and monitored by the MoH and/or agriculture in their respective country; the list of zoonoses has been taken from the Pan-American Health Organization (https://www.paho.org/es/temas/zoonosis).

In section 4, participants were asked to score, based on an absolute category rating, the level and opportunities for OH collaborations in their countries, choosing among: "poor," "fair," "good," "excellent," and "n/a": not applicable. We present these scores in percentages at different institutional and/or professional levels.

In section 5, respondents were asked to evaluate the implementation of the OH approach by the professionals scoring from 1 (poor) to 5 (excellent); to describe formal initiatives to establish intersectoral collaboration; to give their "top 3" environmental, animal health, or public health problems in the last 5 years in their country; to name three institutions responsible for OH in their country; and finally, the level of knowledge about OH of the country inhabitants scoring from 1 (poor) to 4 (excellent). The scoring and type of scale made it possible to transfer the results from a qualitative approach to a quantitative one by giving a score to each answer (18, 19). We present the results using box-plots, to illustrate the median score (plus IQR and min/max) attributed by respondents.

Qualitative data (open questions) were analyzed using content analysis method, thus categorizing, coding, and then identifying different themes and the relationships between them. As regards the question related to One Health definition, we used the Tripartite Zoonotic Guide definition of OH (20) to identify if the answers aligned with the three health components and key terms such as: collaboration, intersectoral, multi-disciplinarity, and better design of health policies. Answers to the question asking for examples of OH initiatives were categorized using the main topics as follows: (i) zoonoses and subclassification of zoonoses (vector borne, food borne), (ii) AMR and themes related to food hygiene, (iii) animal welfare, (iv) answers that did not declare any specific topic of OH approach (e.g., belonging in a OH network or teaching the concept at some level).

Data was organized in Excel (v19) and graphics were created with Excel, Word, Displayer (online) https://www.displayr.com/, and Sankey Flow Show (online) https://www.sankeyflowshow.com/. Descriptive statistics of answers and scores was carried out. We analyzed and presented data in two ways: 1. answers from all participating countries, including Colombia, and 2. answers from all participating countries, excluding Colombia. We included the survey (Spanish version) in **Supplementary Material**. Also, we are available to provide raw data if requested.

RESULTS

General Information

Overall, 76 respondents from 13 countries answered the questionnaire, with at least one respondent per country.

Few countries (Colombia, Mexico, Perú, and Argentina) reached the targeted number of questionnaires answered (3), other countries reached two questionnaires answered (Ecuador, Costa Rica, Chile, Brazil, and Bolivia), and the other ones sent one answer only. Colombia had 42 answers representing 55% of the total (**Figure 1**). In most of the sections of the survey, the results were very similar among analysis with all countries included and without Colombia; we presented the differences when appeared.

Considering the responses from all countries ($n = 76$), almost half of the respondents had a professional degree in animal health or animal husbandry ($n = 37$, 49%), followed by public health ($n = 31$, 40%). Only two respondents stated that they had a professional degree in human health ($n = 2$, 3%). One respondent had professional training/education studies in environmental sciences (1%), one in education (1%), one in economics (1%), one in commerce (1%).

The majority of respondents worked at higher education institutions/universities ($n = 44$, 58%) and governmental institutions/ministries ($n = 8$, 11%); others in research centers ($n = 5$, 7%). Those working in NGOs were 5, 7%; without Colombia ($n = 5$; 24%) and the private sector ($n = 2$, 3%; without Colombia $n = 2$, 9%). Five respondents did not provide details.

The majority of respondents belonged to 45 institutions working in animal health (59%), followed by 15 in public

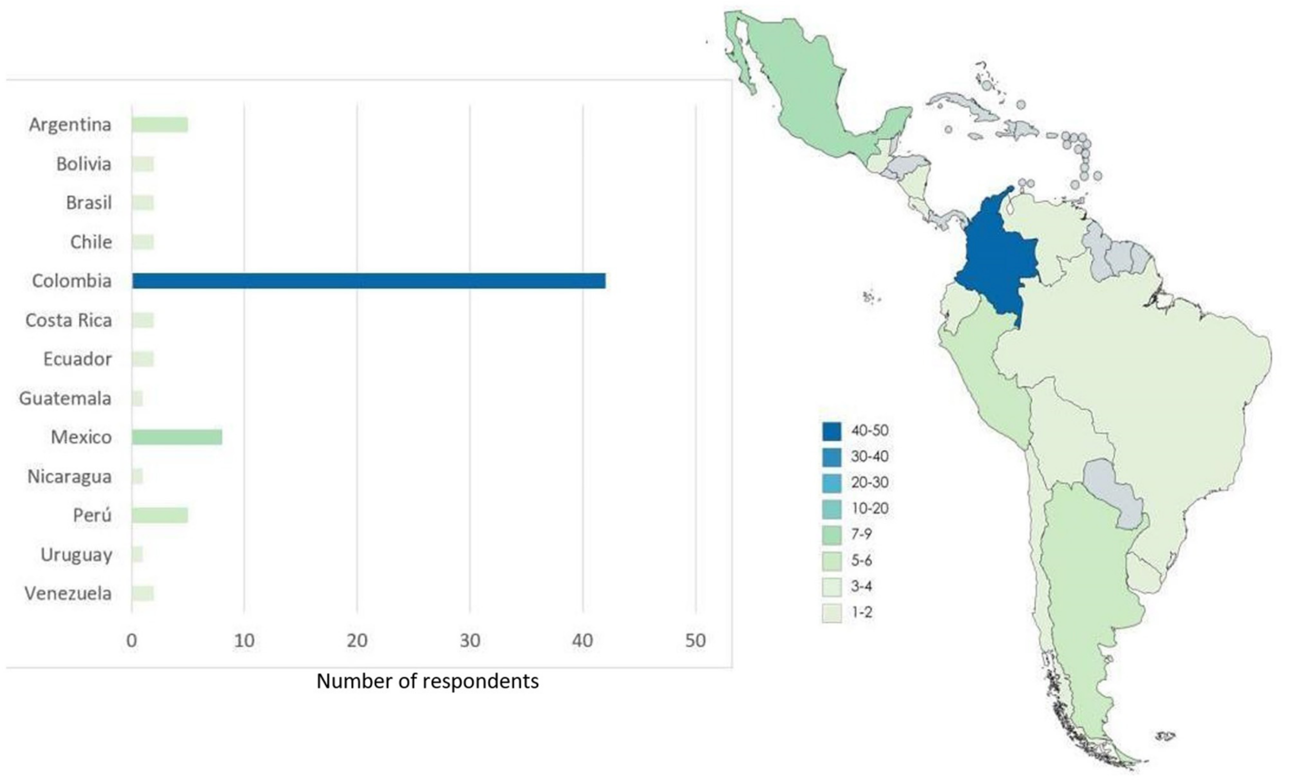

FIGURE 1 | Map illustrating the number of respondents to the questionnaire per country, and bar chart with the number of questionnaires answered. Colors grade from light green (low number of questionnaires answered) to dark blue (high number).

health (20%), and only 7% in human health (n = 5) and 7% in environmental health (n = 5) (**Figure 2**). Veterinary public health respondents worked in the public health sector.

Most of the respondents stated to be professors (n = 26; 34%), heads/directors (n = 17; 22%), and researchers (n = 17; 22%). In less proportion, only 7% of respondents were consultants and others work as vet clinicians (7%). The students and retired compound (6%) of participants.

About One Health

Considering all countries, 70 respondents (92%; without Colombia n = 31, 91%) answered they had heard about OH, while six (8%; without Colombia n = 3, 9%) declared that they had never heard about it. When asked to define OH in one sentence, 52 respondents (68%; without Colombia n = 16, 47%) included the words human, animal, and environmental health as essential components to define OH. However, the words "intersectoral" and "trans/multidisciplinary/holistic" were used by only 17 people (22%; without Colombia n = 11, 32%), 4 named "collaboration/sharing" (5%; without Colombia n = 3, 9%). Finally, 15 participants gave definitions that did not align with the WHO definition of OH or appeared off topic (20%) without Colombia n = 4, 12%. Examples of these answers were: "*Total health,*" "*Healthy,*" "*Wellbeing for everyone and all in harmony.*"

When participants were asked if they were currently involved in OH initiatives, the large majority stated to be involved (n = 52; 68%); this percentage was 77% without Colombia (n = 26). Most people involved had studies in "public health" (n = 25, 48%) followed by "animal husbandry" (n = 24, 46%) and "human health" (n = 1, 2%), environmental health and economic sciences (n = 1 each, 1%; without Colombia n = 1, 4%). On the other side, 24 respondents stated that they were not involved in OH initiatives and most of them (12) belonged to Colombia. Those who declared not to be involved in OH initiatives had a disciplinary studies in animal husbandry (n = 13, 54%; without Colombia n = 3, 43%), public health (n = 7, 29%; without Colombia n = 4, 57%), education, human health, animal health, and commerce (each n = 1, 4%).

The participants were also asked to briefly describe the OH initiatives. Since this was an open answer, we categorized it in: zoonoses in general (20 answers, 38%; without Colombia: 6 answers, 23%); vector-borne zoonoses (n = 7, 13%; without Colombia n = 3, 12%); OH without deepening any specific field (n = 8, 15%; without Colombia n = 3, 12%); antimicrobial resistance (AMR) (n = 5, 10%; without Colombia n = 3, 12%); animal welfare (n = 5, 10%; without Colombia n = 1, 4%); education (n = 3, 6%; without Colombia n = 1; 4%); food hygiene (n = 1, 2%; without Colombia n = 1, 4%); and chemical safety (n = 1, 2%). One Health initiatives on zoonoses were mostly cited by people with an education in "public health" (n = 15), followed by "animal husbandry" (n = 10), and "human health" (n = 1). The respondent with economic background was involved in initiatives on zoonoses (n = 1). Education activities were cited by "animal husbandry" (n = 2) and "public health" people only (n = 1).

Forty-nine respondents stated that OH had been officially endorsed by their institutions, while 7 Institutions did not endorse; 20 respondents said "*No answer/I don't know*." The institutions endorsed OH by implementing initiatives regarding health education (n = 20), research on

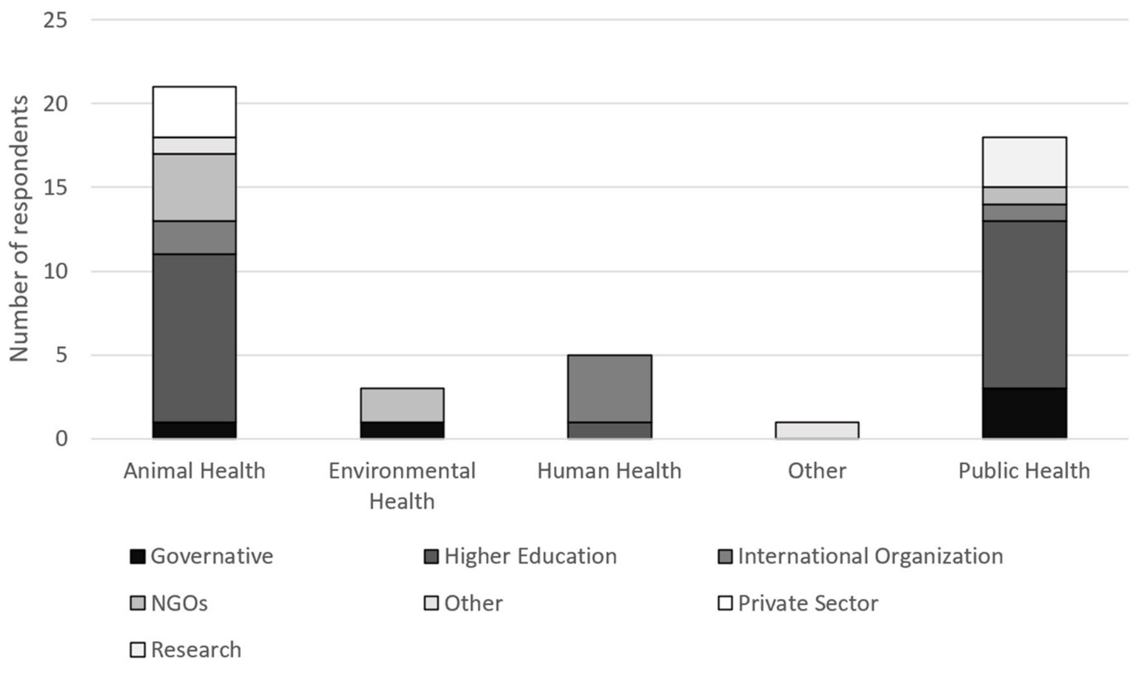

FIGURE 2 | Typology and discipline of institutions by which respondents were employed.

zoonosis/AMR/vector-borne diseases ($n = 14$), zoonoses in general ($n = 5$), public health and public health policy ($n = 5$), one welfare ($n = 3$).

The respondents cited some examples of programs for which a OH approach was adopted in their institutions. These examples mostly referred to zoonoses surveillance and control ($n = 9$), health education ($n = 19$), research ($n = 10$), and environmental health ($n = 3$). Other cited examples were animal health ($n = 2$), and OH in general ($n = 2$). Antimicrobial resistance and One Welfare were cited once.

When asked to score—from 1 (low) to 5 (high)—some advantages of OH described in literature, respondents appeared to consider all the advantages important. In fact, the median score for "Early detection of threat and timely, effective or rapid response," "Better/improved/more effective disease control and/or biosecurity measures," "Improvement in human or animal health or well-being," "Ecosystem benefit," and "Design of health policies" was 5. A score of 4 was given to "Economic benefit/increase in economic efficiency," "Higher quality or larger quantity of information and data and improved knowledge or skills," and "Personal or social benefits," being a high score still. This result did not change when Colombia's responses were excluded.

Around 40% of respondents were aware of the existence of boards/committees/associations actively dealing with OH issues/initiatives in their country (**Figure 3**). Some respondents provided details, stating boards and networks of Physicians and Veterinarians such as: "Public Health Veterinary Council," "Rickettsiosis Program and Vector Borne Diseases" in Mexico; "Antimicrobial Resistance Group" in Brazil; "Coordinating Committee for Research in Animal Health" in Uruguay; "Applied Research Center of Chile (Ciachi)" (https://ciachi.org/es/) and "Health Ministry and Academia" in Chile; "Rabies and Brucellosis National Control Programs" in Guatemala; "Animal health and ecosystem" in Argentina; "Sapuvet network" (https://www.sapuvetnet.org/) in Peru; "National Wildlife Veterinary Council" in Costa Rica; and "National Health Institute," "National Zoonoses Control Program," "One Health Groups from Academia," "One Health Network and Food safety" in Colombia.

Table 1 and **Figures 4**, **5** show the respondents' opinion about the level, nature and duration of such cooperation. As shown, the majority of respondents stated the main advantages were the exchange of data, shared budget, and joint training. Likewise, most of the respondents described the duration of those initiatives to be <10 years (38%). Half of the respondents was not aware of the duration of the OH initiatives.

Twenty-five respondents were aware of 1–5 OH initiatives being implemented, three people indicated 6–10 initiatives, and four respondents more than 10 initiatives. Thirty-nine respondents did not know in which field these initiatives were implemented. Other respondents cited disease surveillance and monitoring ($n = 33$), disease prevention and control ($n = 34$), research ($n = 28$), participants' awareness on the programs ($n = 19$), and higher education programs ($n = 20$). "NextCap" Project in Bolivia and Applied Research Center of Chile (Ciachi) in Chile were cited as local examples of OH projects or programs.

Functional Cooperation in Zoonotic Diseases, Environmental Health, and AMR

Twenty-nine people (38%; without Colombia 18 respondents, 53%) claimed that in their countries there is a functional cooperation between the MoH and the Ministry responsible for Animal Health, facing zoonoses. Twenty-two participants 29% answered "no" (without Colombia: 15 respondents, 44%), and the other interviewees answered "I do not know." **Figures 6A,B** illustrate which zoonotic diseases are controlled and monitored by the MoH and/or Ministry of Agriculture

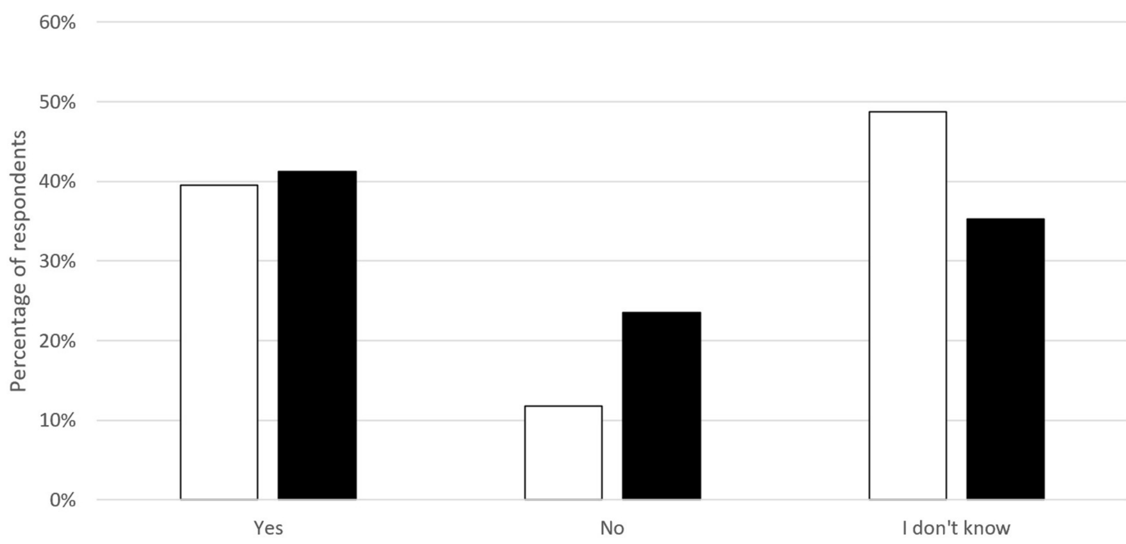

FIGURE 3 | Knowledge about existence of boards/committees/associations actively dealing with One Health issues/initiatives in Latin America; Colombia included (white) and excluded (black).

TABLE 1 | Level of connections on One Health.

	AR	BO	BR	CR	CH	CO	EC	GT	MX	NI	PE	UR	VE
National	17.6%	0	5.8%	5.8%	5.8%	35.3%	0	0	17.6%	5.8%	5.8%	0	0
National-Subnational and local	33.3%	0	0	0	0	66.6%	0	0	0	0	0	0	0
National and subnational	0	0	0	0	12.5%	75%	0	0	12.5%	0	0	0	0
National and local	0	0	0	0		0	0	0	0	0	0	100%	0
Subnational	0	0	0	20%	0	60%	0	0	0	0	20%	0	0
Local	0	0	0	0	0	83.3%	0	0	16.6%	0	0	0	0
Subnational-local	0	0	0	0	0	50%	0	0	0	0	0	0	50%
I don't know	2,5%	5.1%	2.5%	0	2.5%	56.4%	5.1%	2.50%	10.2%	2.5%	7.7%	0	2.5%

AR, Argentina; BO; Bolivia; BR, Brasil; CR, Costa Rica; CH, Chile; CO, Colombia; EC, Ecuador; GT, Guatemala; MX, Mexico; NI, Nicaragua; PE, Perú; UR, Uruguay; VE, Venezuela.

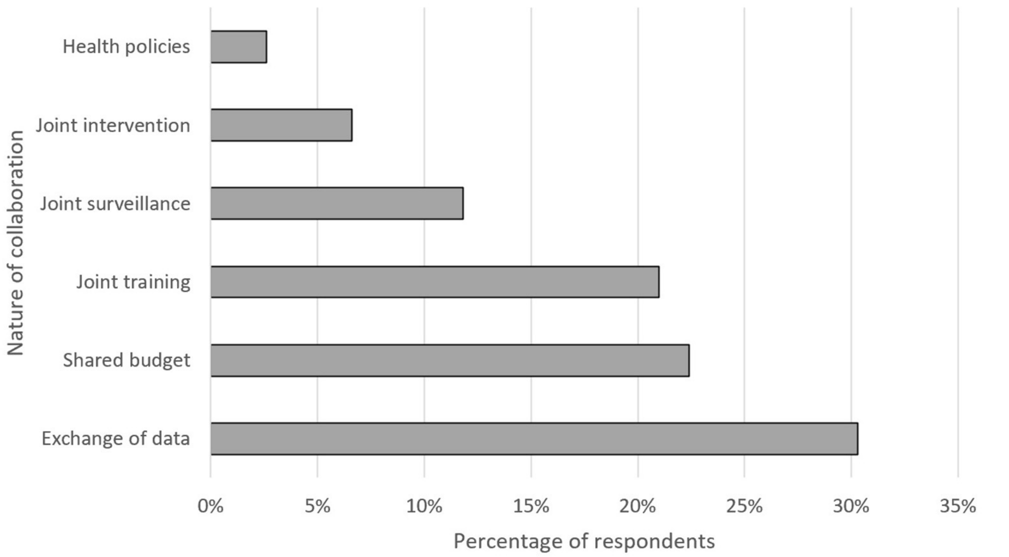

FIGURE 4 | Nature of the collaboration on One Health.

(MoA) in Latin America (Colombia included and excluded), according to respondents.

Some questions sought to interrogate about the level of knowledge in the community about diseases of animals exposed to environmental pollutants and subsequently transmitted to humans by food of animal origin (e.g., dioxins, PCBs, DDT, and related pesticides). Sixty-five respondents (85%) gave a median score of 2 (Q1–Q3: 2–3) to the level of knowledge about these diseases (scoring from 1—poor, to 5—excellent); nine persons said they were not competent in the field. The median score given to the "quality of national plans for the prevention and monitoring of foodborne diseases of animal origin caused by environmental pollutants" by 60 respondents was 3 (Q1–Q3: 2–4). In this case, 16 people responded they were not competent in the field. The results were not altered by withdrawing the respondents from Colombia.

Regarding the issue of AMR surveillance in Latin America, with specific monitoring and research programs, 25 respondents (33%; Colombia excluded $n = 15$ respondents, 44%) declared that their countries contribute to that. Thirteen respondents answer "no" (17%; Colombia excluded $n = 6\%$). The other respondents ($n = 38$, 50%; Colombia excluded $n = 13$, 38%) did not answer or did not know (**Figure 7**).

Factors Limiting Interdisciplinarity and Intersectoral Collaboration

As regards the aspects limiting interdisciplinarity and intersectoral collaboration, the main limit, cited by 27 respondents (36%; Colombia excluded $n = 17$ respondents, 50%), was a "siloed approach" of disciplines, followed by "institutional limits" and "limits on education" cited by six persons each (8% each; Colombia excluded $n = 2$), and "lack of resources" ($n = 2$, 3%; Colombia excluded $n = 2$). Ten respondents mentioned more than one limit. Interestingly, 25 persons (33%) did not answer (Colombia excluded: $n = 13$).

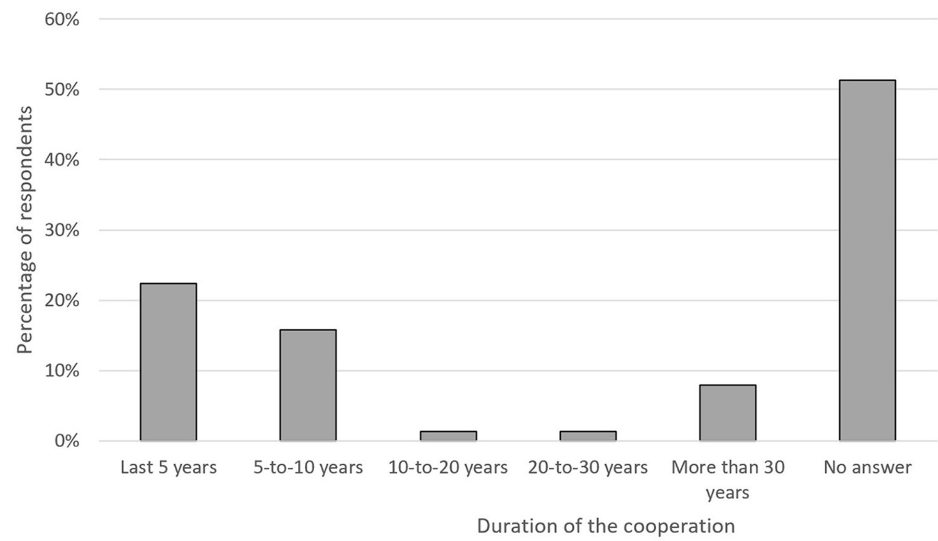

FIGURE 5 | Duration of the cooperation on One Health.

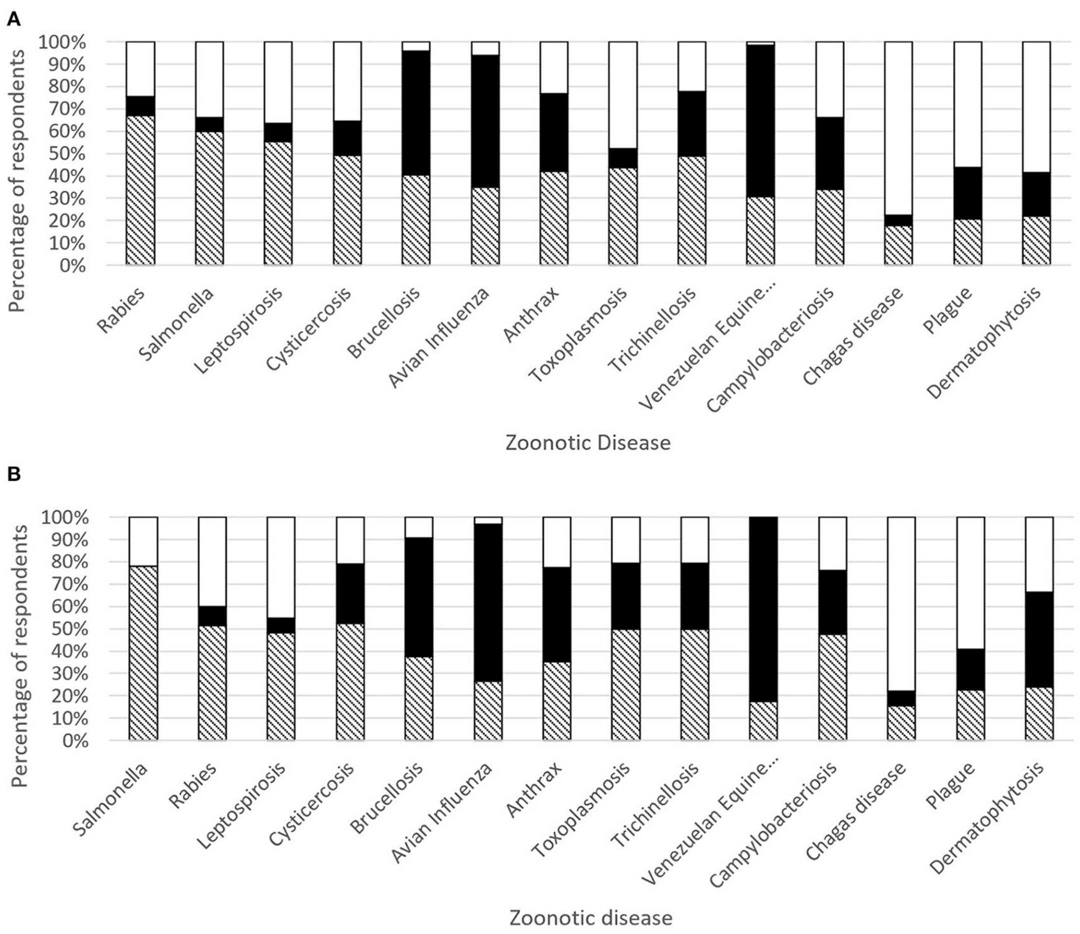

FIGURE 6 | (A) Zoonotic diseases control and monitoring by the Ministry of Health (MoH) in white, Ministry of Agriculture (MoA) in black, and both in black-white stripes in Latin America. **(B)** Zoonotic diseases control and monitoring by the Ministry of Health (MoH) in white, Ministry of Agriculture (MoA) in black, and both in black-white stripes in Latin America (Colombia not included).

Perception on the Level, Opportunities and Implementation for One Health Collaboration

Table 2 shows how the participants perceive the level and the opportunities for OH collaborations within professional boards, University Departments, institutions involved in veterinary surveillance and food security, and institutions involved in emergencies management for both groups. Most respondents agreed that the opportunities for collaboration in all the scenarios described above are poor.

Respondents were asked to rate how well the OH approach is implemented by the professionals employed/engaged in Veterinary, Public, and Environmental Health sectors in their country, scoring from 1 (poor) to 5 (excellent). Seventy respondents gave a median score of 3 (without the results from Colombia, the median score was 3 as well). Details of the answers by countries are illustrated in **Figure 8**. The box-plot illustrates the median score (plus IQR and min/max) attributed by respondents.

Eighteen respondents (24%; Colombia excluded 7 respondents, 21%) asserted the existence of recent formal initiatives to establish and/or to strengthen intersectoral collaboration with the objective of working with a OH approach. Twelve people (16%) answered "no"; the other respondents selected "not answer/I don't know."

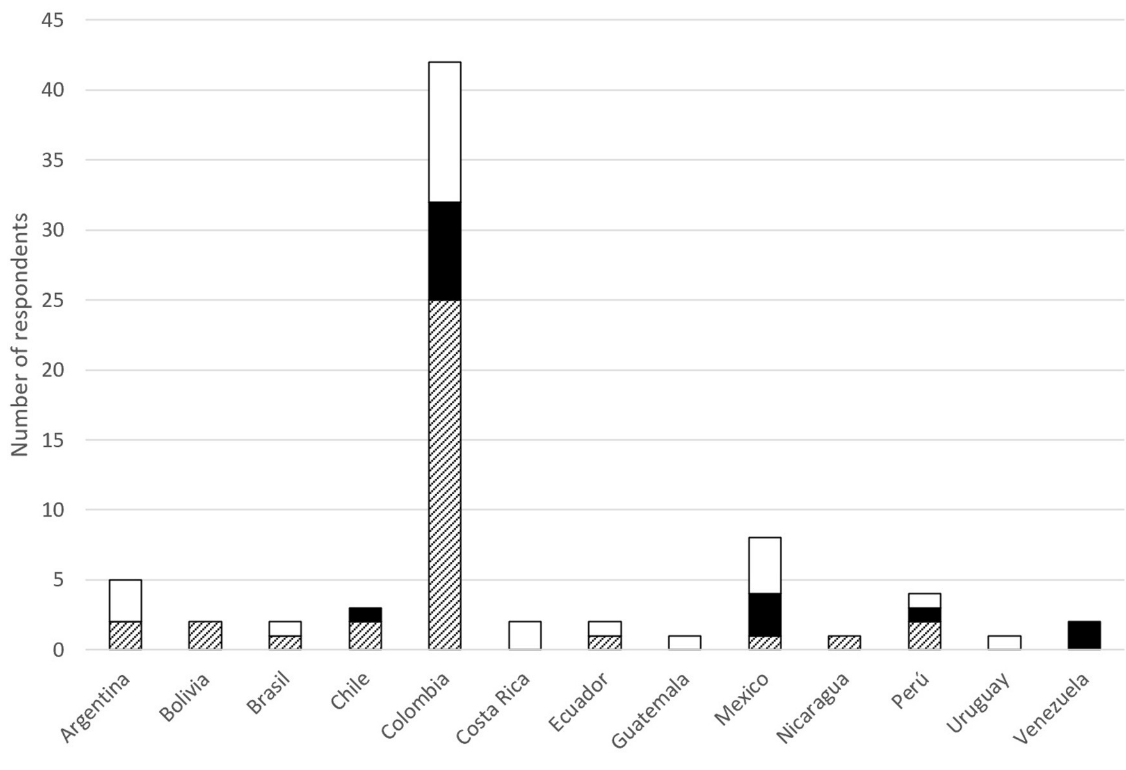

FIGURE 7 | Contribution to Latin America AMR monitoring/research programs, yes (white), no (black), NR (black-white stripes).

TABLE 2 | Perception of the level and the opportunities for OH collaborations within several professional scenarios in both groups (all countries and Colombia excluded).

Level and opportunities for OH collaboration within.	Poor (%)		Fair (%)		Good (%)		Excellent (%)		n/a (%)	
	All countries	Colombia excluded	All countries	Colombia excluded	All countries	Colombia excluded	All countries	Colombia excluded	All countries	Colombia excluded
Professional boards	36 (47.4%)	16 (47.0%)	17 (22.4%)	7 (20.5%)	11 (14.5%)	4 (11.8%)	3 (3.9%)	2 (5.8%)	10 (11.9%)	5 (14.7%)
University Departments	23 (30.3%)	11 (32.3%)	17 (22.4%)	9 (26.5%)	19 (25.0%)	6 (17.6%)	8 (10.5%)	3 (8.8%)	10 (11.9%)	5 (14.7%)
Institutions involved in vet surveillance and food security	31 (40.8%)	13 (38.2%)	24 (31.6%)	12 (35.3%)	14 (18.4%)	5 (14.7%)	1 (1.3%)	1 (2.9%)	7 (19.2%)	3 (8.8%)
Institutions involved in emergencies management	32 (42.1%)	14 (41.2%)	23 (30.3%)	11 (32.3%)	12 (15.8%)	3 (8.8%)	1 (1.3%)	1 (2.9%)	9 (11.8%)	5 (14.7%)

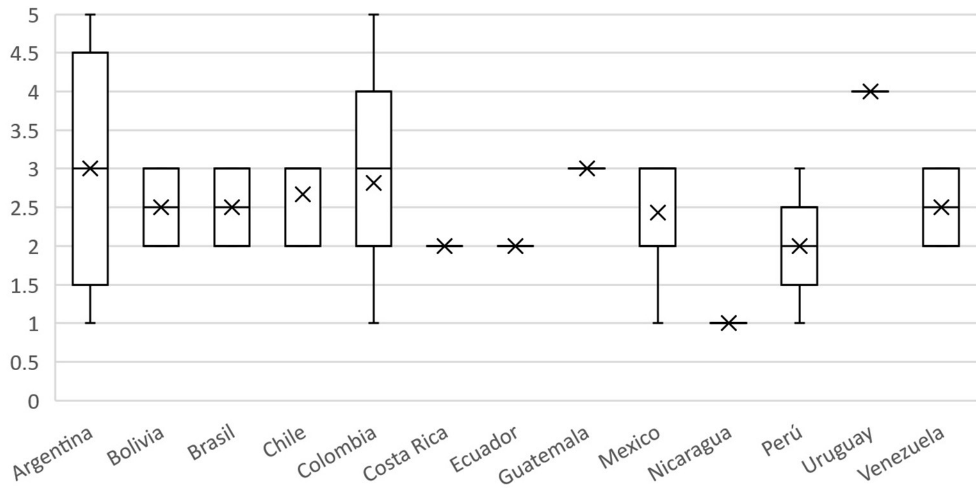

FIGURE 8 | Boxplot of the scores attributed by respondents on the implementation of the OH approach by professionals in their respective countries; scoring from 1 (poor) to 5 (excellent).

Examples of "Burning" OH Issues/Initiatives

The participants were asked to cite the top three environmental, animal, and human health issues in their country over the past 5 years. The vast majority (92%; Colombia excluded: 97%) cited AMR, food safety ($n = 56$, 74%; Colombia excluded: 47%) and zoonoses ($n = 12$, 16%; Colombia excluded: 43%). The Sankey diagram shows all answers by country (**Figure 9**). When considering answers by countries in the same geographical region, we observed differences in the top three issues: AMR was cited in all countries except from Guatemala; food safety in all countries except from Ecuador, Chile, Nicaragua, Guatemala, and Peru; all except Nicaragua, Guatemala, and Peru cited zoonoses.

Gaps in One Health Approaches

Gaps in OH plans were identified as the "siloed approach of disciplines or lack of articulation among sectors" ($n = 26$, 34%), "government barriers/lack of political will and laws to create synergies" ($n = 18$, 24%), "barriers for OH communication/lack of education of OH approach among institutions and citizens" ($n = 9$, 12%), and "lack of resources and budget" ($n = 11$, 14%). Other breaches cited by fewer respondents were that priorities are focused on human health but not on animal and environmental health ($n = 3$, 4%) and the institutional corruption ($n = 1$, 1%). Twenty-three (30%) of the respondents did not answer. From those 23 people, their discipline were animal sciences ($n = 11$), public health ($n = 8$), human health ($n = 1$), commerce ($n = 1$), health education ($n = 1$). From the 23 respondents who did not answer, 13 were from Colombia. When removing Colombia's answers, the results were the same.

According to participants, the level of knowledge/perception of OH amongst citizens/consumers in their country is very low. In fact, the median score was 2 (Q1–Q3: 1.75–3.0) in a range from 1 (poor) to 4 (excellent). Even if we removed Colombia's answers, the median score remained 2. Details of the answers aggregated by countries are illustrated in **Figure 10**. The box-plot illustrates the median score (plus IQR and min/max) attributed by respondents.

Only some respondents added a few comments, remarks and suggestions to the questionnaire: … "*there is a certain apathy from those responsible for human health to integrate animal health professionals into a conjoint work,*" "*…. hopefully the actions in favor of OH will be a priority because of the Pandemic*"…"*Our countries must: 1. receive greater commitment from government institutions. 2. Strengthen training for communities and unions. 3. Include lines of training on One Health in formal primary, secondary and university education programs, as well as in informal training programs* "…" we *should include requirements for OH in health sector legislation, including specific budgeting of resources....*"

DISCUSSION

There is currently no record in Colombia or Latin America that would allow understanding of the OH baseline on perception, knowledge, and barriers among main stakeholders.

General Information

The vast majority of respondents to our survey had a background in animal health and public health, and slighter engagement from the environmental component of OH. Education, commerce, economics, biology, and evolution disciplines 1% each. Chiesa et al. (16), obtained similar results in the European study, where the majority of respondents declared to had training or professional studies in animal health or animal husbandry (54%), followed by Public Health or Human Health (30%), and only 10% of respondents had Environmental Sciences studies. In addition, most of our respondents worked at higher education institutions/universities followed by governmental institutions/ministries, research centers, NGOs, and the private

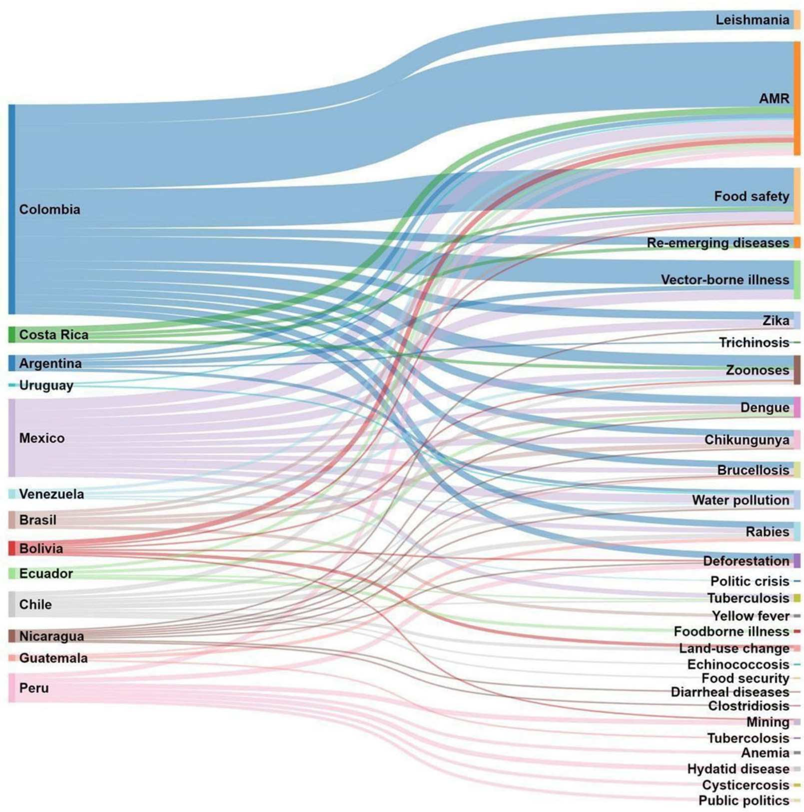

FIGURE 9 | Top environmental, animal, and human health issues over the past 5 years cited by countries in the different regional areas (Colombia excluded).

sector. In the European study, a lower percentage of interviewees worked at Higher Education Institutions/Universities and in NGOs, while there was a higher participation from Governmental Institutions/Ministries, research centers, and private sector. The larger proportion of respondents from animal health, as well as academic and research institutions can be explained by the fact that, in Latin America, OH was first made known in universities with veterinary medicine schools through the Sapuvet network in the 2000s. Since then, the OH concept has been promoted strongly by animal health academy and research communities (8, 13, 14). Also, the European study was carried out during the framework of action of the Network of Evaluation of OH, while in our study the survey was done independently by the initiative of Academia without predetermined resources and Government collaboration.

About One Health

"One Health" was a familiar concept for the majority of respondents (92%). Overall, 68% of respondents mentioned the words human, animal, and environmental health as essential components to define OH. However, the words "intersectoral" and "trans/multidisciplinary/holistic" were used by only 22% (excluding Colombia 32%), and only 5% (without Colombia 9%) mentioned the aspect of "collaboration/sharing." Our results differed moderately from the European study (16), higher percentages of respondents included a term among "intersectoral/transdisciplinary/holistic" in the definition and named "collaboration/sharing." This may be explained by the fact that the OH approach has been studied the most by animal health and public health (21), so a traditional understanding of OH evolving around the linkages between "human," "animal," and "environment" health exists. Only 20% of interviewees did not answer properly or gave an incomplete or unclear definitions, indicating that one-fifth have a lack of understanding of the concept among the knowledgeable audience. This is in accordance to Xie et al. (22), who stated that, despite the OH concept's growing popularity and acceptance by the professional community, the definition of the term remains imprecise. It is important to highlight that the environmental health component was mentioned frequently, in 68% of the answers, which suggests that the three pillars of OH are overall perceived as having equal importance. In contrast, in Europe, only 42% of the respondents mentioned the environment (16) showing that in Latin America the environmental component is taken more into account.

The background of respondents who claimed to work on zoonoses was mostly public health and animal science. The high frequency of people joining OH initiatives on zoonoses is reflected by the significant amount of literature in OH describing the importance of the approach in the control and prevention of zoonoses. Moreover, the major contributions to

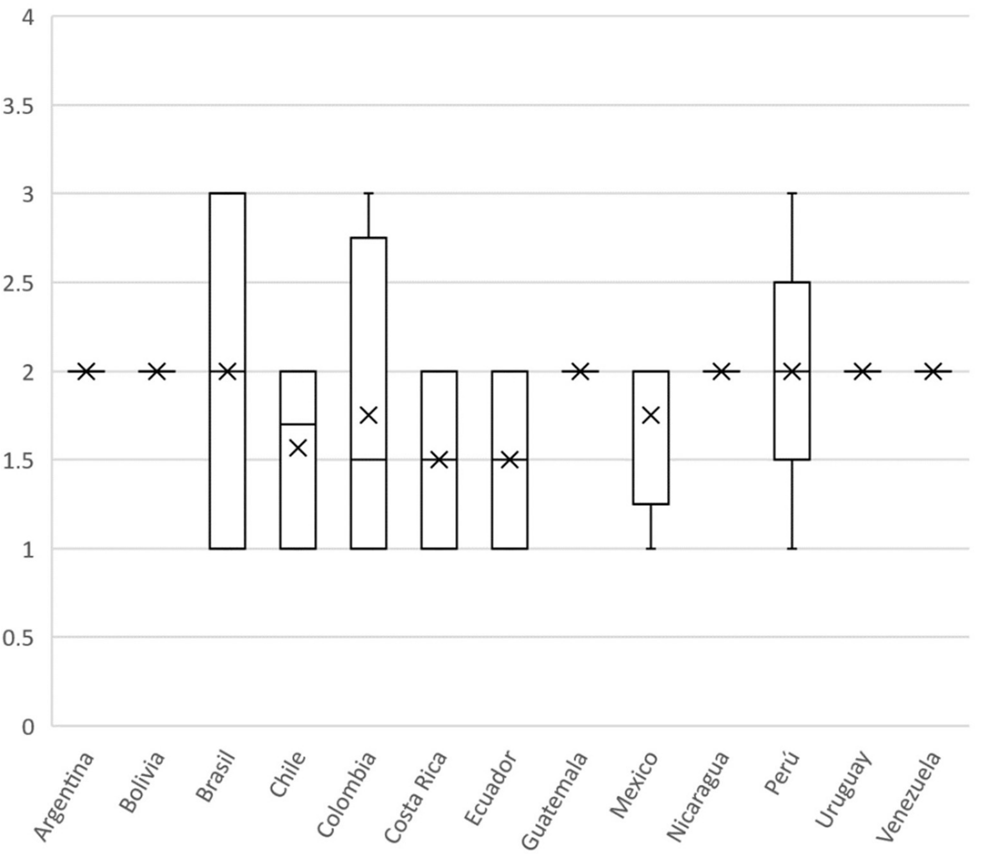

FIGURE 10 | Boxplot of the scores attributed by respondents to the level of awareness on OH in citizens in their respective countries; scoring from 1 (poor) to 4 (excellent).

improve our understanding of complex health relationships and to reduce national and global health risks are carried out on zoonoses topics (20, 23–25). Thus, in order to gain a more in-depth understanding of the socio-economic and ecological determinants of human, animal, and ecosystem health, the OH approach is the most promising way for dealing (prevent and control) with multi-scale, system-wide threats such as pandemics. Regarding that, the United Nations Environment Programme (26) stated that more investment and support is required before such approaches can be implemented routinely. Thus, a standardized set of metrics to measure the effectiveness of OH interventions on zoonoses may also help to increase uptake of the approach (26). In this sense, a National Program for the Integrated Control and Prevention of Zoonoses based on OH approach was designed in Colombia to support the policy decision making for zoonotic diseases in 2016. Lessons learnt from that experience showed that active integrated cooperation to prevent and control zoonoses is adopted only in outbreak situations or public health emergencies but not as continuum systematic way of working among sectors (27). Furthermore, there are limits to data sharing, joint cross-sectoral coordination mechanisms and joint risk assessment among Ministries and a shared budget to implement OH activities or priorities is absent. Despite that, Colombia was pioneer in holding the first CDC-OH Zoonotic Prioritization workshop in Latin American as an example of a collaborative and joint simulation exercise in 2019 (28), providing a good model to engage countries in the OH reflection.

The major advantages and outcomes of OH were identified by our respondents as the early detection of threat and timely, effective or rapid response, better/improved/more effective disease control and/or biosecurity measures, improvement in human or animal health or well-being, ecosystem benefit, and design of health policies. This indicates the importance of OH when dealing with outbreaks from animal origin and when assuring integrated health policies. Lower scores were attributed to other aspects ("Economic benefit/increase in economic efficiency," "Higher quality or larger quantity of information and data and improved knowledge or skills," and "Personal or social benefits"), corroborating the lack of evidence of the added value in economic and research aspects. In Latin American countries, the social, economic, environmental advantages of implementing OH as a way for better health governance is still a long way to go, given the priorities generated by the huge social inequalities.

The fact that about 40% of respondents reported to know formal connections, committees, or initiatives of OH in their country is valuable. However, most of respondents denied or ignored the existence of OH initiatives in their countries (**Figure 3**), which indicates the lack of true integration of activities in field. Several projects and activities have been developed and are now working within the OH concept at the national, regional, and global level, as mentioned in the results, based on the expectation that a more holistic management of microbial health hazards will result in a more efficient use of the scarce resources available for mitigating zoonotic disease risk (20, 24–26). However, such a paradigm shift has not been supported by the systematic allocation of resources to integrated national or multinational programs. As said before, at the national level, Ministries of Health and Agriculture (or Animal Health) remain largely separate, with individual budgets and agendas (20).

The number of interviewees involved in OH initiatives that belonged to "environmental health" sector was low. We acknowledge the potential selection bias in our study because the participation of the environmental sector was limited, although we attempted to contact professionals from this area. However, De Freitas (29) reported that in Latin America, the environmental dimension (ecosystem) has never been taken into account in a systematic way, therefore environmental health professionals do not tend to participate in intersectoral work (29). This could also explain the fragile collaboration between professionals in human health, animal health, and in the ecosystem areas (29). This happens despite six of the countries with the world's greatest biodiversity are found in Latin America: Brazil, Colombia, Ecuador, Mexico, Perú, and Venezuela. This region is also home to the habitat with greatest biodiversity in the world (30). Even if the participation of the environmental professionals was low, almost all respondents (90.8%) considered environmental health a OH pillar.

Zoonotic Diseases, Environmental Health, and AMR: Examples of "Burning" OH Issues/Initiatives

The examples of OH issues/initiatives provided, showed interesting insights. Only 38% of the respondents reported an active cooperation in their countries between the MoH and the Ministry responsible for Animal Health (MoA), when dealing with zoonoses, also stating that there is an obligation to guarantee a reciprocal flux of information between Public Health and Animal Health services. The wildlife diseases that are present in Latin America were not explicitly addressed in our list, because these diseases are underreported and wildlife research is not as closely connected to domestic animals and humans. We know there is an information gap produced by the lack of well-established bodies and surveillance programs for the wildlife diseases, we included only those with recognized surveillance in Latin America countries.

Our study showed that respondents gave importance to classical endemic zoonoses as well as emerging zoonoses as they stated they should be monitored and controlled by both, MoH and MoA. Diseases like rabies, salmonellosis, leptospirosis, cysticercosis, brucellosis, avian influenza, anthrax. In Sankey diagram we noticed that other infectious zoonotic diseases are cited such as: trichinosis, tuberculosis, echinococcosis, and the vector borne diseases (VBD) like zika, chikungunya, dengue, leishmaniasis, yellow fever, indicating that environment aspects should be considered in control and prevention. These results are in accordance with local authors in Colombia who pointed out that influenza A (H1N1), leptospirosis, brucellosis, rabies, and toxoplasmosis are the zoonoses with high priority in 2012 (31). Likewise, in Brasil, Gonçalves, et al. (32) reported that Lyme diseases, brucellosis, leptospirosis and toxoplasmosis are related to the low social, economic and cultural conditions of the population from small rural properties have resulted in lack of basic information on animal health and direct or indirect contact with the various species of domestic animals, wildlife and ticks have probably contributed to the prevalence levels found. The presence of such diseases is seen in marginalized populations, reflecting the lack of equity in our society and the lack of attention to the social determinants of health (SDH) and risk factors (33, 34). Neglected infectious diseases in Latin America are often left out as public health priorities, or their prevention and control programs are underfunded or are deemed unsustainable. The SDH are especially important in Latin American countries, which are characterized by adverse colonial legacies, tremendous social injustice, huge socioeconomic disparities, and wide health inequities (34). Poverty and inequality worsened substantially in the 1980s, 1990s, and early 2000s in these countries (33). Many Latin American countries have introduced public policies that integrate health, social, and economic actions, and have sought to develop health systems that incorporate multisectoral interventions when introducing universal health coverage to improve health and its upstream determinants (33). However, these conditions and factors continue to be present in most of these countries, and a clear long term solution is still needed. Health inequalities and inequities throughout the Americas are persistent and manifest through the occurrence of these diseases, providing crude illustrations of severe deprivation, and misery in vulnerable populations (34). Regarding the complexity of the surveillance, control, and prevention of zoonoses, the need to implement integrated epidemiological surveillance systems for these classical zoonoses in both animal and human health is critical. Important efforts are needed to improve the lack of information on zoonoses due to the poor regional surveillance systems (35). The underreporting of zoonoses in human health has been explained in Colombia by the indifference from the medical doctors about zoonotic diseases, and by the logistic and institutional barriers for laboratory confirmation of those disease (36). Many factors contribute to underreporting of zoonoses, arising from both an inability and an unwillingness to report. The relative importance of these factors varies in different situations, but they often act in combination to stifle the collection and distribution of accurate and comprehensive data, particularly in resource-poor settings (37). In the area of clinical practice, medical schools do not typically emphasize the ecology of microorganisms; so, medical students do not see the importance of zoonotic diseases and the impact on human health, and therefore, they do not see the need to work with their veterinary medical colleagues. This evident gap finds its beginnings from the education of the medical school, where the focus is only on the human being. Contrary to that, veterinary medicine seeks to teach students about different species, including humans, which allows a more obvious will to collaborate with other areas (38).

The Sankey diagram (**Figure 9**) shows that the most frequent health problem mentioned in Latin America was AMR. However, 50% of the participants stated, answering another question in the survey (**Figure 7**), that they did not know if their respective countries contribute to AMR surveillance with specific monitoring and research programs. To the authors' knowledge, AMR surveillance is one of the best examples of the impact of the OH approach in practice in the Region. Indeed, since 2010, there has been a strong commitment from FAO, OIE, and PAHO, working together to mitigate the risks of AMR in the interconnection among human health, animal health, and the environment. With participation of representatives of Ministries of Health and Agriculture from Argentina, Brazil, Chile, Colombia, Paraguay, Peru, and Uruguay, the organizations now joined forces in the implementation of the project "Working Together to Fight Antimicrobial Resistance" to ensure a coherent "One Health" approach, recognizing the multidimensionality, and necessity of an intersectoral response that is needed to address the problem of AMR (39). Among the 25 respondents (33%) who were aware of AMR initiatives in their countries, only 6 (from Colombia and Ecuador) mentioned the FAO, OIE PAHO initiative described above. Other initiatives described were from Argentina, Chile, Perú, Brazil, Uruguay, but the names of the programs or projects were not mentioned. It is perplexing that none of the participants from Colombia, mentioned the Colombian Integrated Program for Antimicrobial Resistance Surveillance (COIPARS), a program created for AMR surveillance in poultry farms that was the first initiative to explore the implementation of OH (40).

Aspects Limiting Interdisciplinarity/Intersectorality in OH

In the section regarding the aspects limiting interdisciplinarity and intersectorality in OH (section 4), the "siloed approach" of sectors, followed by the siloed approach of disciplines, was the most commonly mentioned limiting factor (34%). This factor has long been recognized as a barrier to moving toward OH by several authors worldwide (41–43). Johnson et al. (41) reported that the absence of a clear definition and subsequent vision for the future of OH act as a barrier to interdisciplinary collaboration, and that siloed approaches/lack of communication by different sectors restrict the ability for professionals to work collaboratively across disciplines (41). In the same way, Manlove et al. (42) stated that efficiently disseminating knowledge and methodologies across disciplinary boundaries is essential for a cohesive reaction to emerging threats. However, researchers tend to organize themselves into discipline-specific "silos" that contain robust internal research communities, but that only rarely interact with one another. This is particularly true of the disciplines studying infectious disease: workplaces range from hospitals, to microbiological laboratories, to ecological field sites, to mathematical computing facilities, and communicating across these physical and cultural boundaries is difficult (42). Likewise, Nyatanyi et al. (43) reported the Rwanda's government need to fund the implementation and embrace the concept of "oneness," such that the separate ministries can develop common policies, approaches and evaluations that can feed into action plans and improved health infrastructure. Academics also need to think beyond the traditional silos (medicine, public health, veterinary medicine, engineering, etc.) in ways that will stimulate innovation and encourage problem solving (43).

Concerning the other gaps that emerged from our study, the general low awareness about OH, lack of implementation about OH, lack of commitment of policy-makers, resources, and budget for OH. Chiesa et al. reported similar results in their study in Europe (16). We compared our findings with the classification reported by Ribeiro et al. (44). They offered the challenges and difficulties for executing OH initiatives in the following three categories: 1. *Conditions for starting*: policy and funding; education and training; 2. *Execution*: surveillance; multi-actor, multi-domain, and multi-level collaborations; and 3. *Monitoring and evaluation*: evidence (44). Based on this classification, several barriers were cited in our study as follows in policy and funding: "*lack of funding, normative and inclusion of research results within the Governmental sector, "low political will," "personnel reluctant to change*." On the education and training, obstacles were cited as follows: "*lack of awareness on these topics from the human health sector,*" "*insufficient training programs on OH concept and application*." Referring to the surveillance level, one respondent answered: "*logistical challenges such as lack of personnel supporting the environmental component in national programs*" "*Need of diagnostic laboratory capacity for wildlife,*" "*ambiguous legislation for integrated surveillance across different domains (environmental, animal, and human health systems,*" "*Restricted access to data, conflict of interest, selfishness, and lack of interest on those topics*." On the multi-actor collaboration and multi-domain collaboration, difficulties were described as: "*the little opening of each sector for collaborative work,*" "*Sectors work in isolated way,*" "*difficulties in promoting the engagement of multiple actors across domains*." Regarding the multi-level collaborations, problems were cited as: "*…institutional corruption…Colombians have unhealthy practices in the search of resources to maintain their families due to social inequities" "Professional egos hindering the intersectoral collaboration*." Dos Ribeiro et al. (44) reported the lack of OH evaluation studies and reporting of outcomes and lack of guidelines and metrics for OH monitoring and evaluation but in our study, we did not find any answer about these specific challenges.

As regards the perception of the level and the opportunities for OH collaborations within several professional scenarios (**Table 2**) the "poor" scores prevailed as regards professional boards, institutions involved in animal surveillance and food security and institutions involved in emergencies management. This result suggests that in Colombia and the other participating countries there is an overall negative perception about OH collaboration, despite its potential benefits. According to our data, there is a common understanding that OH is beneficial to design and implement better public health programs, but the implementation of the OH approach remains a huge challenge (**Figure 8**). One Health implementation is qualified between *insufficient* and *limited* in all participating countries. This is in accordance with Yamada et al. (45), who pointed out that OH operationalization has so far proved to be challenging. Implementation is often a complex issue requiring collaboration between diverse and multi-disciplinary partnerships (45). At a local or national level, it often might be a matter of breaking down professional barriers through improved communication and incorporating information on OH and its benefits into professional training and university courses. At the international level, it is usually much more difficult and can be hindered by dysfunctions which characterize current forms of global health governance (45). Regardless of the gaps and barriers mentioned by participants for the OH implementation, Pettan-Brewer et al. (46) reported that local communities from diverse social and economic status, including indigenous populations, have been working with institutions and social organizations for many years, especially in Brazil, accomplishing results through grassroots movements. These "bottom-up" socio-community approaches, have been also tools for prevention and control diseases (46).

Limitations of This Study

Although the questionnaire was sent by email to key contacts from OH networks existing in the Region, only 13 countries answered the questionnaire, with at least one respondent per country. The Latin America region is made up of 21 countries and the Latin America and the Caribbean region is made up of 46 countries (47). The participation of at least two professionals from each of the three areas was expected in each Latin American country, since there is no contact in the Caribbean region. That is, we obtained approximately 60% of the expected response rate. The mode of distribution of the survey somewhat limited the number of responses, due to the fact that our study was an independent investigation. In this sense, Cole (48), in his comparative study between web surveys and surveys sent by mail, ensures that surveys that reach personal mail with their own name, are 39% more likely to be answered than those that are posted on the web or they are sent by a third party. According to the same author, web surveys or surveys sent by third parties have a possibility of approximately 16.6% of being opened by people, but without submitting any response. This was observed in our study given that three people started to respond but gave up at some point. In the case of our study, the vast majority of respondents to the survey were professionals known by one of the authors and to whom the survey was sent to their respective personal emails with its own name. The apparent low participation may be a consequence of the breakdown of the OH union in Latin America, since the people belonging to each key area have not been clearly identified. However, since the participation to this survey was completely voluntary, the lack of interest to join this survey can be an indicator of the barriers for the operationalization of OH initiatives in the Region.

Our study differed from the European one on the sampling method, due to the lack of a baseline database of professionals working within this OH approach in Latin America. The survey form was firstly distributed to professionals from the Sapuvet network and the professional connections of the authors working in the government (public health and animal health) or in other high education institutions knowing or applying the concept of OH in Colombia. This may have created a bias on the type respondents who participated in the study, as the respondents from Colombia were more than a half (55%). Indeed, a known systemic network of OH in the region was absent at the time of the circulation of the survey. Besides, authors did not have control over how the survey reached the government in each country if so.

However, the results were analyzed in two different ways, one including Colombia and another one omitting Colombia's answers; when comparing these groups of analysis, results were very similar. We consider that other countries that did not participate in this survey could have similar results. Indeed, the OH concept became increasingly known as the norm to work during the response to the 2009–2010 influenza pandemic at the global, regional, national, and community level (49), but progress on the adoption and implementation of this approach has been slow in the Americas region. However, it is possible that in countries such as Brazil and Mexico, with a history of stronger OH collaboration, the perception and knowledge in this field may be different, due to the presence of avian flu (H1N1) in Mexico in 2009 (50), and in Brazil due to the PAHO Office presence and influence. In a recent publication, Pettan-Brewer et al. (46), reported that OH Brazil network has been a successful example to all other countries of inclusive and sustainable interdisciplinary partnerships uniting a country with national and international collaborations through OH. The network has established mutual official partnerships with organizations such as One Health Platform, One Health Initiative, One Health Commission, One Health Sweden, continuing to build solid partnerships among uncountable international organizations from all continents (46).

Another limitation of our study was the low participation of environmental science professionals in this survey. Although an attempt was made to contact and to invite professionals from the environmental sector no response was obtained. This limitation is also described by the World Bank stating that while environment is one of three main sectors in the concept of OH, in practice it is systematically underrepresented. The chronic lack of economic, and even ecological data available on impacts to the environment sector was a recurring discussion point (15). Nonetheless, some authors affirm that among the problems to include and to gather ecosystem field in the Latin American countries are the institutional weakness (absent or precarious human, technical, and financial resources), resulting in absent or discontinuous ecosystem monitoring programs, with low quality of available data (29). Briggs et al. (51), also provided evidence of the limited documentation, coverage, and accessibility of information about environmental initiatives in Latin America. More recently, Vizeu-Pinheiro et al. (52), unveil that most countries in Latin America have environmental laws but there are gaps between the laws and implementation in practice, also they revealed a great variation across countries and dimensions of environmental governance. The Environmental Rule of Law Regulatory agencies face implementation challenges, driven in part by constraints on human and financial capacity. While the region shows progress on environmental impact assessments, progress is still needed toward producing comprehensive explanations of agency decisions. Within civic engagement, the region has made progress on access to information but public participation remains a challenge and the rights of environmental defenders are a huge concern (52).

In the particular case of Colombia, Agudelo et al. (53) mentioned that from 2001 to 2014, some laws and plans, regarding the environment and its connectedness with health were created, as for example, the Public Health Ten-Year plan (53). In this Plan, the dimension called Environmental Health includes programs toward the prevention and control of zoonoses, the water and sanitation quality, the air quality and impact of pollution, the control of vector-borne diseases and vector control, the solid waste management, the surveillance of environmental risk factors, among others. This is a great improvement regarding environmental health, but it is premature to say that the changes are evident at this time (53, 54), because in the rural settings of the country, long historic social gaps have been indicating the abandonment of the Colombian State with the rural populations, especially people belonging to indigenous and afro descendants' groups. Those populations have the worst indicators in health, in terms of the maternal mortality rates, access to clean water, to primary health services, to sanitation of waste management and good house quality (55). In this way, we agree with Garnier et al. (56), pointing out that integrating a gender perspective together with the vision, traditional knowledge, and needs of Indigenous Peoples and Local communities, into a multi-sectoral OH approach, would greatly enhance biodiversity conservation, global health, and sustainable development outcomes. An organized approach to build collaborations between practitioners, community, and academia under the gender perspective, could improve environmental integration, biodiversity conservation, and OH implementation in Latin America, as women have a pivotal role in managing and conserving natural resources in the current challenges that emerge at the Human-Animal Environment interface (56). We believe that in Latin America countries there are auspicious biological and cultural scenarios to integrate a framework of gender-responsive and right based OH Approach that could help reverse the environmental, health, and climate degradation and loss of biodiversity and doing this becoming an example of socio-ecological resilience.

Finally, authors consider these results reflect a perceived need for change from a fragmented health organization to an integrated health response to global challenges not only in Colombia but also in other Latin America countries. We emphasize the urgency to integrate a framework for OH governance. In this sense, the stages of policy development based on knowledge integration (KI) as a mechanism for multi-institutional learning to improve the governance, and coordination of OH implementation as described by Hitziger et al. (57) are recommended. Along the development of health policies, the KI can be used to build a common framework enabling an understanding of the links between the knowledge of multiple individuals. In practice KI is a multidimensional challenge because it requires the integration of cognitive concepts, organizational, and social interests and perspectives as well as communicative and cultural factors. As shown in our results (**Figures 8**, **10**), respondents attributed low scores to the level of implementation and awareness of OH in citizens, echoing how insufficient and limited the approach is in for the participants. The integration of the three forms of knowledge throughout a policy cycle can be facilitated by three different approaches: multicriteria analyses for target knowledge, systems thinking for systems knowledge and transdisciplinary approaches for transformation knowledge (57).

In these particular times, health programs are targeting an integrative approach for COVID-19, considering the role of OH initiatives (46). The year 2020 was key, since governments around the globe reviewed their progress on the Sustainable Development Goals, the Paris Agreement and the Convention on Biological Diversity. What we are going through as a species confirms the importance of accepting a new global agreement between nature and people. The most important lessons learned from this health, social, and environmental crisis in Latin America are: (i) the need for more efficient and transparent management of resources that allows greater equity and access to health services, (ii) the importance of strengthening health education competencies at the community level, and (iii) the urgency to develop a greater degree of empathy toward all the species with whom we inhabit the planet, among others. The current framework of the human-animal-ecosystem interface in Colombia and some of the other Latin America countries is affected by fragmentation of health interests, programs, and sectors, a general lack of societal participation and by professional focus on very limited areas of expertise. In this way, we consider that integration and implementation of the OH approach can support countries to improve their health policies and health governance as well as to advocate the social, economic, and environmental sustainability of the Region.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethical approval was granted by the Clinical Research and Ethical Review Board at the Royal Veterinary

College, grant holder of COST Action TD1404 NEOH (ref. prot. n. URN 2016 1554). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

The article is the result of a survey. NC: senior author supervising the writing, translation of the survey, general coordination and supervision of the questionnaire distribution, managing questionnaire answers, and drafting and editing manuscript. LT, FC, and DM: conceptualization and design of the questionnaire survey. AO: data cleaning and managing questionnaire answers, data management and analysis, snd creation of figures and tables. NC, AO, LT, FC, and DM: survey and article editing. All authors reviewing the final version of the manuscript.

ACKNOWLEDGMENTS

The authors would like to thank: Dr. Luis E. Escobar (Virginia Tech, US) for his inspiring work on One Health field in Latin America; Dr. Simon Rüegg and Dr. Barbara Haesler for their support sharing key contacts in Latin America countries to participate in the survey; SAPUVETNET III members, who shared and answered this survey; Dr. Diego Soler (Universidad de La Salle, Colombia) for introducing us to the members of the OHLAIC Network and sharing the emails of people who might be interested in this subject; Dr. Juan Carlos Carrascal (One Health Colombia); Dr. Christina Pettan-Brewer (University of Washington, US); Dr. Daniela Figueroa and Dr. Sergio Scott (Chile) for their important contribution to One Health in Latin America, generating opportunities to cooperate among many different sectors and disciplines.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2021.649240/full#supplementary-material

REFERENCES

1. FAO/OIE/WHO. *High-Level Technical Meeting to Address Health Risks at the Human-Animal Ecosystems Interfaces*. Mexico City (2012).
2. Zinsstag JM, Schelling IEB. From 'two medicines' to 'One Health' and beyond. *Onderstepoort J Vet Res*. (2012) 79:492. doi: 10.4102/ojvr.v79i2.492
3. WHO. *One health*. WHO (2020). Available online at: http://www.who.int/features/qa/one-health/en/ (accessed 17 February, 2021).
4. Monath TP, Kahn LH, Kaplan B. One health perspective. *ILAR J*. (2010) 51:193–8. doi: 10.1093/ilar.51.3.193
5. Rabinowitz PM, Kock R, Kachani M, Kunkel R, Thomas J, Gilbert J, et al. Toward proof of concept of a one health approach to disease prediction and control. *Emerg. Infect. Dis*. (2013) 19:e130265. doi: 10.3201/eid1912.130265
6. Ristl CL, Arriola CS, Rubin C. Prioritizing zoonoses: a proposed one health tool for collaborative decision-making. *PLoS ONE*. (2014) 9:e109986. doi: 10.1371/journal.pone.0109986
7. Okello AL, Gibbs EP, Vandersmissen A, Welburn SC. One Health and the neglected zoonoses: turning rhetoric into reality. *Vet Rec*. (2011) 169:281–5. doi: 10.1136/vr.d5378
8. Zinsstag J, Schelling E, Waltner-Toews, Tanner M. From 'one medicine' to the 'one health' and systemic approaches to health and well-being. *Prev Vet Med*. (2011) 101:148–56 doi: 10.1016/j.prevetmed.2010.07.003
9. Rüegg SR, Nielsen LR, Buttigieg SC, Santa M, Aragrande M, Canali M, et al. A systems approach to evaluate OH initiatives. *Front Vet Sci*. (2018) 5:23. doi: 10.3389/fvets.2018.00023
10. Rüegg SR, Buttigieg SC, Goutard FL, Binot A, Morand S, Thys S, et al. Editorial: Concepts and experiences in framing, integration and evaluation of One Health and Ecohealth. *Front Vet Sci*. (2019) 6:155. doi: 10.3389/fvets.2019.00155
11. Carrascal Velásquez JC, Pettan-Brewer KC, Pastrana Puche NE, González Meza JH, Botero Serna YP, Figueroa D, et al. *2nd One Health Colombia International Symposium OHCIS2019*. (2019). Available online at: https://repositorio.unicordoba.edu.co/bitstream/handle/ucordoba/2532/LIBRO_DE_RESÚMENES_OHCIS2019.pdf?sequence=9andisAllowed=y (accessed September 12, 2021).
12. *2nd International One Health Symposium Proceedings*. Available online at: https://repositorio.unicordoba.edu.co/handle/ucordoba/2532 (accessed March 14, 2021).
13. Ortega C. Importancia de la salud pública veterinaria en la actualidad: el proyecto SAPUVET. *Rev Sci Tech Off Int Epiz*. (2004) 23:841–9. doi: 10.20506/rst.23.3.1527
14. Ortega C, Villamil LC, Cediel N, Rosenfeld C, de Meneghi D, de Rosa M, et al. Las redes SAPUVET y SPVet: un modelo de integración en materia de salud pública veterinaria entre Europa y América Latina. *Rev Panam Salud Públ*. (2005) 17:60–5. doi: 10.1590/S1020-49892005000100011
15. World Bank. *One Health: Operational Framework for Strengthening Human, Animal, and Environmental Public Health Systems at Their Interface. 1st ed*. Washington, DC: World Bank (2018). Available online at: http://documents.worldbank.org/curated/en/703711517234402168/Operational-framework-for-strengthening-human-animal-and-environmental-public-health-systems-at-their-interface (accessed 18 February 2021).
16. Chiesa F, Tomassone L, Savic S, Bellato A, Mihalca AD, Modry D, et al. A survey on one health perception and experiences in Europe and neighboring areas. *Front Public Health*. (2021) 9:609949. doi: 10.3389/fpubh.2021.609949
17. Naderifar M, Goli H, Ghaljaie F. Snowball sampling: a purposeful method of sampling in qualitative research. *Strides Dev Med Educ*. (2017) 14:1–4. doi: 10.5812/sdme.67670
18. International Telecommunication Union. *Subjective Video Quality Assessment Methods for Multimedia Applications*. (2021). Telecommunication Standardization Sector of ITU. Available online at: https://www.itu.int/rec/dologin_pub.asp?lang=e&id=T-REC-P.910-199608-S!!PDF-E&type=items (accessed February 12, 2021).
19. Henchoz Y, Meylan L, Santos-Eggimann B. Intervals between response choices on a single-item measure of quality of life. *Health Qual Life Outcomes*. (2016) 14:41. doi: 10.1186/s12955-016-0443-5
20. World Health Organization (WHO), Food and Agriculture Organization of the United Nations (FAO) and World Organisation for Animal Health (OIE). *Taking a Multisectoral, One Health Approach: A Tripartite Guide to Addressing Zoonotic Diseases in Countries*. (2019). Available online at: https://www.who.int/initiatives/tripartite-zoonosis-guide (accessed July 27, 2021).
21. Hristovski M, Cvetkovik A, Cvetkovik I, Dukoska V. Concept of one health - a new professional imperative. *Maced J Med Sci*. (2010) 3:229–32. doi: 10.3889/MJMS.1857-5773.2010.0131
22. Xie T, Liu W, Anderson BD, Liu X, Gray GC. A system dynamics approach to understanding the One Health concept. *PLoS ONE*. (2017) 12:e0184430. doi: 10.1371/journal.pone.0184430
23. Zinsstag J, Schelling E, Waltner-Toews D, Whittaker M, Tanner M. *One Health: The Theory and Practice of Integrated Health Approaches*. Wallingford: CABI (2015).
24. Haesler B, Cornelsen L, Bennani H, Rushton J. A review of the metrics for One Health benefits. *Rev Sci Tech*. (2014) 33:453–64 doi: 10.20506/rst.33.2.2294

25. Rüegg SR, McMahon BJ, Häsler B, Esposito R, Nielsen LR, Ifejika Speranza C, et al. A blueprint to evaluate one health. *Front Public Health.* (2017) 5:20. doi: 10.3389/fpubh.2017.00020
26. United Nations Environment Programme and International Livestock Research Institute. *Preventing The Next Pandemic: Zoonotic Diseases and How to Break the Chain of Transmission*. Nairobi (2020).
27. Ministerio de Salud y Protección Social, Organización Panamericana de la Salud, Universidad de La Salle. *National Integrated and Integral Program of Zoonoses.* (2016). Available online at: https://www.minsalud.gov.co/sites/rid/Lists/BibliotecaDigital/RIDE/VS/PP/SA/Propuesta-intregada-programa-zoonosis.pdf (accessed September 1, 2021).
28. CDC. *One Health Zoonotic Disease Prioritization Workshops.* (2019). Available online at: https://www.cdc.gov/onehealth/what-we-do/zoonotic-disease-prioritization/completed-workshops.html#colombia (accessed September 1, 2021).
29. de Freitas CM, de Oliveira SG, Schütz GE, Freitas MB, Camponovo MP. Ecosystem approaches and health in Latin America. *Cadern Saúde Públ.* (2007) 23:283–96. doi: 10.1590/S0102-311X2007000200004
30. UNEP-WCMC. *El estado de la biodiversidad en América Latina y el Caribe*. UNEP-WCMC, Cambridge, Reino Unido (2016). Available online at: https://www.cbd.int/gbo/gbo4/utlook-grulac-es.pdf (accessed September 1, 2021).
31. Cediel N, Villamil LC, Romero J, Renteria L, De Meneghi D. Setting priorities for surveillance, prevention, and control of zoonoses in Bogotá, Colombia. *Rev Panam Salud Publ*. (2013) 33:316–24. doi: 10.1590/s1020-49892013000500002
32. Gonçalves DD, Benitez A, Lopes-Mori FMR, Alves LA, Freire RL, et al. Zoonoses in humans from small rural properties in Jataizinho, Parana, Brazil. *Braz J Microbiol.* (2013) 44:125–31.
33. De Andrade LO, Pellegrini Filho A, Solar O, Rígoli F, de Salazar LM, Serrate PC, et al. Social determinants of health, universal health coverage, and sustainable development: case studies from Latin American countries. *Lancet.* (2015) 385:1343–51. doi: 10.1016/S0140-6736(14)61494-X
34. Pan American Health Organization. *Social Determinants of Health in the Americas*. (2021). Available online at: Pan American Health Organization: https://www.paho.org/salud-en-las-americas-2017/?p=45 (accessed August 23, 2021).
35. Garza-Ramos J. La situación actual de las zoonosis más frecuentes en México. *Gaceta Méd México.* (2010) 430–6.
36. Agudelo-Suárez AN, Villamil-Jiménez LC. Políticas públicas de zoonosis en Colombia, 1975-2014. Un abordaje desde la ciencia política y la salud pública. *Rev Salud Pública.* (2017) 19:787–94. doi: 10.15446/rsap.v19n6.72109
37. Halliday J, Daborn C, Auty H, Mtema Z, Lembo T, Bronsvoort BM, et al. Bringing together emerging and endemic zoonoses surveillance: shared challenges and a common solution. *Philos Trans R Soc Lond. B Biol Sci.* (2012) *367*:2872–80. doi: 10.1098/rstb.2011.0362
38. Lerner H, Berg C. The concept of health in One Health and some practical implications for research and education: what is One Health?. *Infect Ecol Epidemiol*. (2015) 5:25300. doi: 10.3402/iee.v5.25300
39. PAHO-FAO-OIE. *Working Together to Fight Antimicrobial Resistance*. (2020). Available online at: https://www.paho.org/en/together-fight-antimicrobial-resistance
40. Donado-Godoy P, Castellanos R, Leon M, Arevalo A, Clavijo V, Bernal J, et al. The establishment of the Colombian Integrated Program for Antimicrobial Resistance Surveillance (COIPARS): a pilot project on poultry farms, slaughterhouses and retail market. *Zoon Publ Health*. (2015) 62(Suppl. 1):58–69. doi: 10.1111/zph.12192
41. Johnson I, Hansen A, Bi P. The challenges of implementing an integrated One Health surveillance system in Australia. *Zoon Publ Health*. (2018) 65:e229–36. doi: 10.1111/zph.12433
42. Manlove KR, Walker JG, Craft ME, Huyvaert KP, Joseph MB, Miller RS, et al. "One health" or three? Publication silos among the one health disciplines. *PLoS Biol.* (2016) 14:e1002448. doi: 10.1371/journal.pbio.1002448
43. Nyatanyi T, Wilkes M, McDermott H, et al. Implementing One Health as an integrated approach to health in Rwanda. *BMJ Glob Health.* (2017) 2:e000121. doi: 10.1136/bmjgh-2016-000121
44. dos Ribeiro C, van de Burgwal LHM, Regeer BJ. Overcoming challenges for designing and implementing the One Health approach: a systematic review of the literature. *One Health*. (2019) 7:100085. doi: 10.1016/j.onehlt.2019.100085
45. Yamada A, Kahn LH, Kaplan B, Monath TP, Woodall J, Conti L. *Confronting Emerging Zoonoses: The OH Paradigm*. Cham: Springer (2014).
46. Pettan-Brewer C, Martins A, Paiva D, Pérola A, Soeiro D, Figueroa D, et al.. From the approach to the concept: One Health in Latin America - experiences and perspectives in Brazil, Chile, and Colombia. *Front. Public Health.* (2021) 9:687110. doi: 10.3389/fpubh.2021.687110
47. Latin American Network Information Center. *Países en América Latina y el Caribe - LANIC - Español.* Available online at: http://lanic.utexas.edu/subject/countries/indexesp.html (accessed February 18, 2021).
48. Cole ST. Comparing mail and web-based survey distribution methods: results of surveys to leisure travel retailers. *J Travel Res.* (2005) 43:422–30. doi: 10.1177/0047287505274655
49. WHO. *High-Level Technical Meeting to Address Health Risks at the Human-Animal Ecosystems Interfaces.* Mexico city.
50. Mena I, Nelson MI, Quezada-Monroy F, Dutta J, Cortes-Fernández R, Lara-Puente JH, et al. (2016). Origins of the 2009 H1N1 influenza pandemic in swine in Mexico. *Elife*. (2016) 5:e16777. doi: 10.7554/eLife.16777
51. Briggs L, Trautmann N M, Fournier C. Environmental education in Latin American and the Caribbean: the challenges and limitations of conducting a systematic review of evaluation and research. *Environ Educ Res.* (2018) 24: 1631–54. doi: 10.1080/13504622.2018.1499015
52. Vizeu-Pinheiro M, Rojas-Sánchez L, Long SC, Ponce A. *Environmental Governance Indicators for Latin America and the Caribbean.* (2020).
53. Agudelo N, Villamil LC. Políticas de zoonosis en Colombia: del 1 de Salud Pública (PDSP) 2012-2021 (2018). Available online at: https://www.minsalud.gov.co/plandecenal/Paginas/home2013.aspx (accessed February 18, 2021).
54. Organización Panamericana de la Salud – Ministerio de Salud de Colombia. *Propuesta de Programa Nacional Integral e Integrado de Zoonosis (PNIIZ) SCON2016-00326.* (2016). Available online at: https://www.minsalud.gov.co/sites/rid/Lists/BibliotecaDigital/RIDE/VS/PP/SA/Propuesta-intregada-programa-zoonosis.pdf (accessed September 1, 2021).
55. Ministerio de Salud y Protección Social. *Clase Social y salud. Resumen ejecutivo*. Informe Técnico ONS/Octava Edición/2016-2 (2021). Available online at: https://www.ins.gov.co/Direcciones/ONS/Resumenes%20Ejecutivos/Resumen%20ejecutivo%20informe%208%20Clase%20social%20y%20salud.pdf (accessed February 18, 2021).
56. Garnier J, Savic S, Boriani E, Bagnol B, Häsler B, Kock R. Helping to heal nature and ourselves through human-rights-based and gender-responsive One Health. *One Health Outlook*. (2020). 2, 22. doi: 10.1186/s42522-020-00029-0
57. Hitziger M, Esposito R, Canali M, Aragrande M, Häslerd B, Rüegg S. Knowledge integration in One Health policy formulation, implementation and evaluation. *Bull World Health Organ.* (2018) 96:211–8. doi: 10.2471/BLT.17.202705

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The handling editor is currently organizing a research topic with one of the authors NC.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

frontiers in Public Health

PERSPECTIVE
published: 16 November 2021
doi: 10.3389/fpubh.2021.654410

Needs for a Curricular Change in Primary and Secondary Education From the One Health Perspective: A Pilot Study on Pneumonia in Schools

Francisca Marchant [1†], María Pilar Sánchez [2†], Ximena G. Duprat [3†], Alejandro Mena [4†], Marcela Sjöberg-Herrera [5†], Soledad Cabal [6†] and Daniela P. Figueroa [7,8†]*

[1] Department of Chemical Engineering and Biotechnology, Center for Biotechnology and Bioengineering (CeBiB), University of Chile, Santiago, Chile, [2] Department of Biology, Faculty of Chemistry and Biology, University of Santiago, Santiago, Chile, [3] One Health One World Laboratory, Applied Research Center of Chile (CIACHI), Science and Education Foundation, Santiago, Chile, [4] Faculty of Veterinary Medicine, University Mesoamericana, Puebla, Mexico, [5] Department of Molecular Genetics and Microbiology, Faculty of Biological Sciences, Pontificia Universidad Católica de Chile, Santiago, Chile, [6] San José of the Precious Blood High School, Quinta Normal, Santiago, Chile, [7] Ecophysiological Modelling Laboratory, Liberal Arts Faculty, Adolfo Ibáñez University, Santiago, Chile, [8] Eco-models & Climate Change Laboratory, Applied Research Center of Chile (CIACHI) Science and Education Foundation, Santiago, Chile

OPEN ACCESS

Edited by:
Christina Pettan-Brewer, University of Washington, United States

Reviewed by:
Juana Paola Correa Galaz, Universidad San Sebastián, Chile
George Lueddeke, University of Pretoria, South Africa

***Correspondence:**
María Pilar Sánchez
mariapilar.sanchez@usach.cl

† These authors have contributed equally to this work

Specialty section:
This article was submitted to Planetary Health, a section of the journal Frontiers in Public Health

Received: *16 January 2021*
Accepted: *18 October 2021*
Published: *16 November 2021*

Citation:
Marchant F, Sánchez MP, Duprat XG, Mena A, Sjöberg-Herrera M, Cabal S and Figueroa DP (2021) Needs for a Curricular Change in Primary and Secondary Education From the One Health Perspective: A Pilot Study on Pneumonia in Schools. Front. Public Health 9:654410. doi: 10.3389/fpubh.2021.654410

This is the first pilot study on alternative conceptions and obstacles pertaining to pneumonia in adolescents of different school vulnerability indexes. Countries with low socioeconomic levels are disproportionately affected, with Latin America and the Caribbean (LAC) being the second-most affected area in the world, after sub-Saharan Africa. In spite of this fact, pneumonia is not included as an important component within the contents of the microbiology curriculum unit in the natural science school program. Therefore, we wanted to study how students knew about this topic by putting One Health into action by building and validating qualitative and quantitative questionnaires, put together by different experts in pedagogy, didactics, microbiology, and veterinary to find out what students knew about pneumonia and their misconceptions about it. A total of 148 students (in 8th and 9th grade) participated in this survey. The results reveal that no statistically significant differences between the different scholar grades ($p = 0.3360$ Pearson chi^2) or genders ($p = 0.8000$ Fisher's exact test) presented higher or lower School Vulnerability Index (SVI). Regardless of the social stratum or the level of vulnerability of the students, they have heard about this disease primarily through their family/relatives, maintaining a superficial notion of the disease, learning wrong ideas about microorganisms and treatments that can contribute to the risk to public health.

Keywords: alternative conceptions, school vulnerability index, pneumonia, public health, One Health education

INTRODUCTION

Pneumonia is a common and potentially serious infection that has a significant prevalence in childhood and causes 15% of all deaths of children under 5 years of age (1). When pneumonia is acquired in a community environment, it is called community-acquired pneumonia (CAP). This disease can be caused by bacteria, such as *Streptococcus pneumoniae*, *Haemophilus influenzae*, *Mycoplasma pneumoniae*, *Chlamydophila pneumoniae*, and viruses including SARS-COV2, Human parainfluenza viruses, and Influenza viruses, among others (2). Countries with a low socioeconomic level are disproportionately affected by CAP, with Latin America and the Caribbean (LAC) being the second most affected area in the world, after sub-Saharan Africa (3). Usual contact with pets is a risk factor for CAP (4) and this is a serious health problem that could be mitigated with adequate access to nutrition, water, energy, clean air, immunization, health, and education services under the One Health approach (5, 6).

In order to design measures to mitigate the impact on health of a disease such as COVID-19, it is important to understand the causal factors, the infectious cycle, and its transmission (7, 8). Education plays a predominant role in understanding these factors, since infectious diseases can be prevented with basic biosecurity measures. Therefore, education must provide scientific literacy to society, fostering critical thinking when facing events such as pandemics, because in the age of the anthropocene, processes like urbanization, globalization, and industrialization have made the world more vulnerable to pandemics than ever before (9). One Health can help provide an effective international "antidote" to such pandemics (10) and serves as an ideal framework for developing problem-focused curricula that promote interdisciplinary teamwork (11).

Undoubtedly, receiving education about infectious diseases from an early age is of great importance, as it helps to improve alertness in children, reducing the risks of contamination due to harmful microorganisms that may get in contact with them and also their animals (pets and cattle) (12). An early introduction to the One Health educational experience to students will allow them to have a more complete and integrative vision on health issues, as it happens in some high school programs in Sweden and the United States (13).

Then, to begin education, it is important to first measure the notions that a person possesses, either by experience or by what they have learned in their schooling years, which are called alternative conceptions (AC). The importance of considering the ideas that students bring to the classroom lies in the need to guide their learning toward the construction of knowledge. This can be accomplished through scientific research work, including creative activities of scientific work, the formulation of hypotheses or the elaboration of experimental designs (14). An obstacle to overcome, for both children and adults, is difficulty in understanding how you get an infectious disease, what causes it to spread, and how it can be prevented (12).

Although the AC reveals the way in which children have represented the natural phenomena with whom they have been involved, it often happens that these conceptions present mistakes. This is a great obstacle and generally involves an incoherence between the interpretations of the world and scientific knowledge. This type of science-related obstacles in AC can be explained by multiple factors; for example, one obstacle can be the culture through which the child was raised as a student (15, 16). For this reason, the purpose of this work is to know the AC on pneumonia (human/animal) in children of different vulnerability indices, in order to expand the knowledge and show to the ministries the importance of educating in One Health from the first years of school.

METHODS

A cross-sectional pilot study was used to evaluate the effects of health education on knowledge about (human/animal) pneumonia in Chilean secondary students, through the comparison of AC. The target population of this study comprised 8th grade (13–16 years) and 9th (13–17 years) grade school students located in Estación Central, La Florida, and Quinta Normal communes in the Metropolitan Region, Chile. Each municipal school was requested to take a survey, and 4 out of 15 responded and authorized taking it (sample of convenience). These communes were selected according to the school vulnerability index (SVI), from high vulnerability (SVI1) to low vulnerability (SVI3) (17).

The survey consisted of 12 questions broken down into two parts: (i) characterize the student's AC on pneumonia (human/animal) as a concept and mental model in adolescents through three open-ended questions, and (ii) measure AC through nine closed questions with four alternatives (**Supplementary Figures 1**, **2**). The survey was given in a biology class for a period of 20–30 min in duration, previously agreed with the teacher/professor of that class. The students were seated in isolation and all doubts were clarified before taking the survey. The survey was building by different experts in pedagogy, didactics, microbiology and veterinary and validated by experts in microbiology and biological science teaching, according to: (a) feasibility (characteristics associated with the time spent completing the survey, the format, the interest, clarity and briefness of the questions, as well as the ease of scoring); (b) reliability (characteristic related to reproducibility); and (c) validity (refer to the ability of a survey to measure what it has been designed).

Once the survey was completed, the data obtained were analyzed externally by an expert in biostatistics. To perform the analysis of the information collected, ATLAS.ti v.7.5.7 software was used to process and analyse the information related to drawings and explanations of the students. Data entry was performed using Microsoft Excel 2010 (Microsoft Office, Redmond, WA, USA) for determining the percentage of correct answers in each of the participants in this study. Stata MP v 13.1 software (STATA Corp LP, USA) was used for statistical analysis. A significance level of $\alpha = 0.05$, was considered in all statistical tests applied in this study. All the variables of the study were summarized as mean and standard deviation or frequency and percentage.

This research was approved by the Research Ethics Committee of the University of Santiago of Chile. All participants indicated their willingness to participate in this research, with the consent of their parents and the authorization of each school. For this purpose, the names of each student were omitted, in order not to expose the privacy of their participants, which were sequentially labeled from school 1 to 4.

RESULTS

A total of 15 educational establishments were selected according to SVI, but only 4 (26.7%) of them met the inclusion criteria (informed consent obtained from the participants prior to the survey) to be part of this research. Sixty-nine students belonged to 8th grade and a total of 79 students were in 9th grade. The age range of the 8th grade students fluctuated between 12 and 15 years, while that of the 9th grade students varied between 14 and 17 years of age (**Supplementary Table 1**). In total, six groups of students were studied: three groups corresponding to 8th and 9th grade, each one classified in SVI1 to SVI3.

According to the different parts of the survey, the answers of varying complexity were obtained, both about the drawings and their respective explanations about pneumonia, as well as the responses selected in the alternative questions. The survey results were classified into categories: qualitative (part I) and quantitative (part II).

In relation to the characterization of AC about pneumonia (part I), within the most prevalent answers, and according to the qualitative analysis, it was determined that for both 8th and 9th grade students, the physiological-anatomical approach was the one that predominated the most in the sample studied. It was characterized by drawings like the **Supplementary Table 2A**, some of the answers from 8th and 9th grade students in accordance with the SVI related to the organs and structures that make up the respiratory system (nose, pharynx, bronchi, lungs, thorax, and diaphragm, among other parts). In this Table, the PRS code was assigned to indicate "Physiological Respiratory System." This explanatory model accounts for the macroscopic vision that students have with respect to pneumonia.

It would be expected to find in 8th grade students and in 9th grade students (who were taught microbiology in 7th grade and cell in 8th grade), slightly more complex explanatory models that consider concepts such as prokaryotic cell, bacteria, virus, infection, immune system, contagion, and among others.

Interestingly, students in both levels (8th and 9th) with the greatest vulnerability (SVI1) have heard more about pneumonia (**Figures 1A,B**) and found out through a physician from their own experience, that is, because the children became ill with pneumonia. Students in the 8th grade provided a wider variety of responses, while in 9th grade, the AC was clearer that pneumonia is mainly related to the lungs. According to the knowledge about pneumonia (part II), $<20\%$ admit not having heard about pneumonia, all of them belonging to high vulnerability schools (SVI1). The most common source of information about pneumonia in both levels (8th and 9th) was the family, and only one student mentioned the school as a source of information (**Figures 1C,D**, zero values were excluded in the construction of the Figure).

Another AC is related to the belief that the bloodstream is the main transmission mechanism of pneumonia when, in reality, it is saliva droplets contaminated with the pathogen, which can come into contact with the host in multiple ways (SVI1).

Despite the fact that students recognize that the best measure in case of suspected pneumonia is to consult a physician, this option was selected as the second most frequent in all groups. Self-medication with antibiotics dominated as AC in the students from the most vulnerable schools and is accompanied by the idea that getting vaccinated once sick, it could be a measure to consider as possible in case of having the disease. Although most students understood that antibiotics are the adequate pharmacological treatment for pneumonia, most students also answered that the disease was caused by viruses and must be treated with antibiotics, which is contradictory as antibiotics are not used to treat viral diseases.

Additionally, vaccines appear as the second most frequent option for treatment. This is also an obstacle in their explanatory models because vaccines are not exclusive to viruses. In relation to comparison of the number of correct answers in schools according to SVI, when comparing the number of correct answers at the different levels, that there are no statistically significant differences with p-values obtained; almost all are greater than $\alpha = 0.05$ (significance level). The only exception occurred when comparing the percentage of correct answers between the 8th grade schools with SVI2 and SVI3. In global terms, it can be observed that the most vulnerable students answered a lower number of correct answers than the least vulnerable students, both in 8th and 9th grade.

When comparing schools according to their vulnerability index and educational level (**Supplementary Table 2B**), statistically significant differences were found only for the 8th grade (Kruskal–Wallis test, $p = 0.0313$). Schools with a vulnerability index that gave statistically significant differences were schools with SVI1 and SVI3 and schools with SVI2 and SVI3 (Dunn test), p-value 0.0423 and 0.0044, respectively. In the case of 9th grade, no statistically significant differences were found (Kruskal–Wallis, $p = 0.2078$). These results indicate that the different SVI have no relationship on the type of AC that the students in this research may have on pneumonia, and that regardless of the socioeconomic and cultural context in which these contents are taught, students are likely to have similar notions about the disease.

The distribution of the responses of the surveys applied and answered is shown in **Supplementary Tables 3–5** (Correct survey choices, total correct answers, and distribution according to SVI and level).

DISCUSSION

Among the main findings of our research, we detected that the students have the concept associated with pneumonia at the physiological-anatomical level, while we would expect to find that the students consider the explanatory models a little more complex in relation to the causes of the disease. In addition, students belonging to schools with greater vulnerability have less knowledge of the concept of pneumonia and their main source of information is family (relatives). Interestingly, we found that students were unaware that the third cause of death in Chile is pneumonia, which is caused mainly by bacterial agents. This information was less known among students from institutions with a higher degree of vulnerability. On the other hand, regarding the measure in a suspected case of pneumonia, most of the students knew they should go to a physician, but at least half indicated that it could be treated with antibiotics,

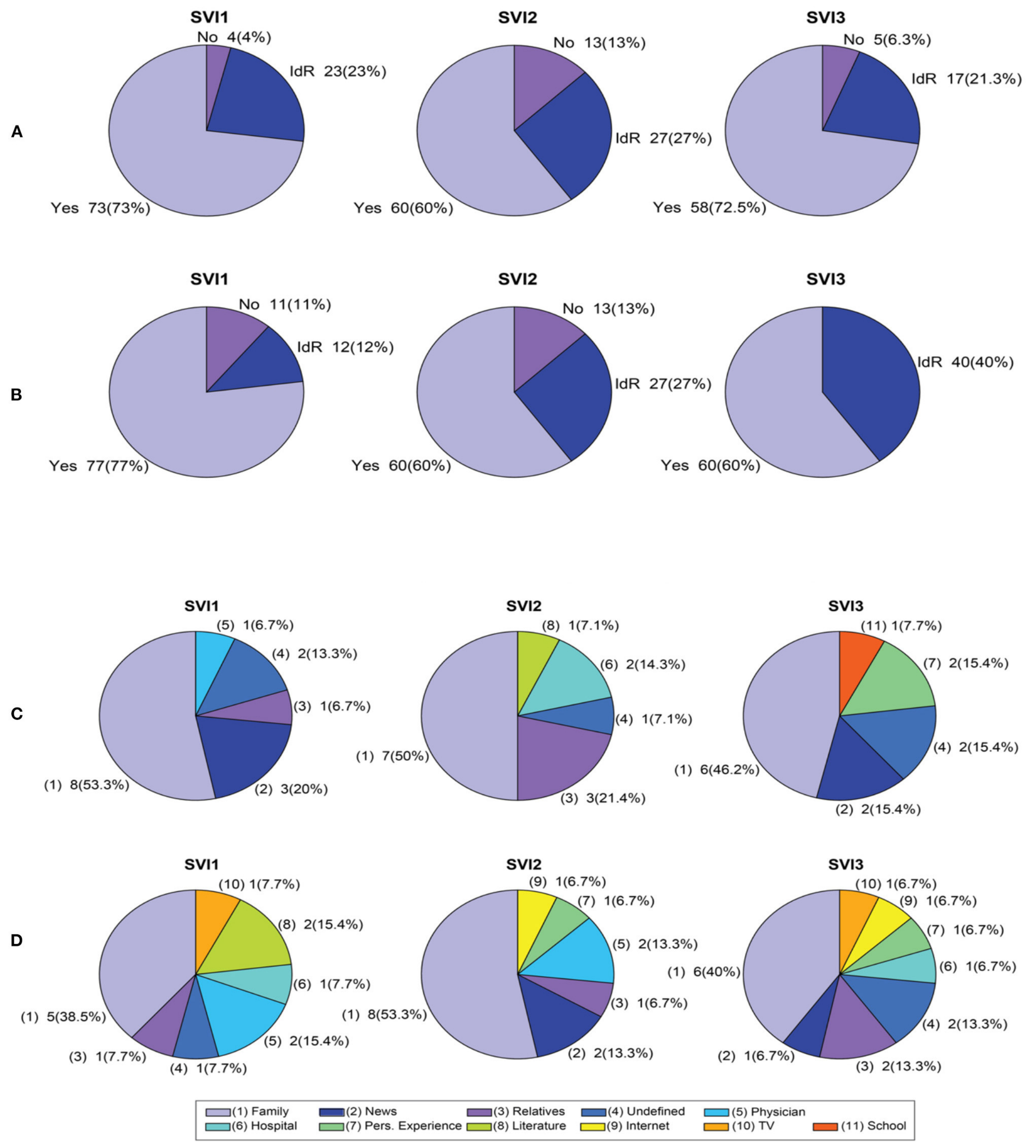

FIGURE 1 | Distribution of responses (in %) according to SVI, Question 2: Have you heard about pneumonia? (Part 1), **(A)** 8th and **(B)** 9th. Frequency distribution of responses by SVI according to source of information Question 2: How did you know? (Part 2), **(C)** 8th and **(D)** 9th. *Zero values were excluded in the construction of the **(C,D)**.

vaccines, and even a healthy diet. This result may have been affected by the curricular contents of Natural Science of 8th and 9th grade. For 8th grade, the most relevant systems of the human body were taught, including the Respiratory System, a reason that could explain why the 9th grade students responded more accurately.

Also, students thought that viral pneumonia can be treated with antibacterials and that vaccines are only used to treat viruses (18). This AC contains two issues: (i) the vaccine is associated as a treatment and not as a preventative tool, and (ii) pneumonia was caused by a virus, which could explain why students consider the vaccine as a treatment against this type of pathogens.

These misconceptions are the main problem that can contribute to public health risk (19) and increase resistance to antibacterials. In general, we found that students who participated in this study have similar notions about pneumonia regardless of their SVI. Perhaps this is due to the lack of understanding of the real scope of this infectious disease in the community, due to the low coverage and quality of education in Chile (20, 21). Chile performs academically below the average of the OECD countries (22). To improve this perception, science teachers must be able to project contextualized teaching in new social settings, with the aim of re-educating citizens so they are capable of facing the future (23). Considering that Chile has the highest incidence of SARS-CoV-2 worldwide with more than 29,803 cases per million (24), it is important to educate the population about the diseases, learn to recognize its symptoms in time, have access to vaccines and precautions, and avoid infection as much as possible. In the training, identification of principal signs of relative diseases that can be transmitted from animals to humans (zoonoses) need to be considered, so they will be prepared to prevent outbreaks and dissemination, protecting themselves (8).

Therefore, it is necessary to implement the development of a public policy for health education with the One Health work strategy. This requires an interdisciplinary approach (animal, human and environmental professionals) optimizing the use of available resources (25). In this sense, One Health approach programs have been designed and implemented through workshops that use activities based on experience and research to teach concepts of pathogen transmission, disease risk assessment, and mitigation (26).

The term pneumonia could be used with the name human/animal pneumonia for the students (must of them won't know that are the same pathogens), because the etiology and clinical signs are similar, so this could help in the detection of pneumonia not only in humans, also in animals because they can be infected with pneumonia and the students will be prepared to report or make an alert about this disease in the animal field too.

Pneumonia can affect domestic animals that can be in contact with humans, like dogs, cats, and cattle. Etiological agents like *Bordetella bronchiseptica*, *Rhodococcus equi*, or *Capnocytophaga canimorsus* can be found in the oral cavity of these animals and be transmitted to humans through bites or direct contact with fluids (27). This is important under the One Health approach because this type of study, and the integration of disease information to the signatures can be implemented with other infections, like vector-borne diseases, zoonoses, etc. So if the students are trained in their schools, they will be able to detect on time, prevent and report diseases in humans and animals. This could be key in their own protection and prevention of future pandemics.

For example, OH Sweden has developed an educational strategy program to promote understanding the interaction between pathogens, hosts, and the environment in a didactic way, through the interaction of students and researchers (13). The OH Training and Leadership program improves household and personal hygiene practices and animal housing in low-income, high-risk communities in South Africa (28). Rwanda has developed educational tools on One Health at the government level in its environmental, livestock and health plans; encouraging the resolution of problems related to infectious diseases in all professions (25). The implementation of an educational system with the One Health concept allows for an early diagnosis and timely treatment of pneumonia, and a reduction of hospital expenses (∼$6,000 US) (29). Like other emerging diseases, One Health concept can also allow preventative measures to mitigate the presence of pneumonia through exposure to urban air pollutants (30).

Chilean public policy for education must implement the One Health concept and it should be located at the level of: Ministry of Education, all providers of public health services (Ministry of Health), financial agents (Ministry of Economy) and the scientific community.

Our study has some limitations: This research only focuses on one discipline, so transdisciplinary perspectives can generate hypotheses that a discipline perspective may miss. Second, we only collected data on knowledge of pneumonia without gender differentiation. This data is important to consider, as women have been reported to be more concerned with maintaining hygiene compared to men (31). Despite these limitations, this study demonstrates the importance of infectious disease education and provides a reference to promote preventive behaviors among Latin American students. This study provides valuable information on the issues that must be prioritized and improved to prevent infectious diseases. We propose the establishment of strategic actions integrated by a network of various agents with the objective of improving education in Chile under the One Health concept.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Research Ethics Committee of the University of Santiago of Chile. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

SC and DF conceived and designed the project. SC performed experiments. SC, MS, and FM analyzed the data. MS, DF, and FM interpreted the data. DF, XD, FM, and MS discussed data and wrote the manuscript. DF, MS-H, MS, AM, and XD reviewed and edited the manuscript. All authors read and approved the final manuscript.

FUNDING

MS was supported by the research grant CONICYT/FONDECYT/REGULAR No. 1171004.

ACKNOWLEDGMENTS

We thank the parents of all surveyed students for giving us their consent to allow their children to participate in the study. We also thank the school administrators for their support in carrying out this research. We thank the valuable contributions of Ing. We appreciate the possibility of collaboration with the funds of the CYTED-USCC Network 412RT0117. Rodrigo Sánchez Olavarría, Dr. Carol Joglar, and Dr. Sergio Scott.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2021.654410/full#supplementary-material

REFERENCES

1. McAllister DA, Liu L, Shi T, Chu Y, Reed C, Burrows J, et al. Global, regional, and national estimates of pneumonia morbidity and mortality in children younger than 5 years between 2000 and 2015: a systematic analysis. *Lancet Glob Health.* (2019) 7:e47–e57. doi: 10.1016/S2214-109X(18)30408-X
2. Musher DM, Thorner AR. Community-Acquired Pneumonia. *N Engl J Med.* (2014) 371:1619–28. doi: 10.1056/NEJMra1312885
3. Iannella HA, Luna CM. Community-acquired pneumonia in Latin America. *Semin Respir Crit Care Med.* (2016) 37:868–75. doi: 10.1055/s-0036-1592076
4. Méndez-Brich M, Serra-Prat M, Palomera E, Vendrell E, Morón N, Boixeda R, et al. Social determinants of community-acquired pneumonia: differences by age groups. *Arch Bronconeumol.* (2019) 55:447–9. doi: 10.1016/j.arbres.2018.12.012
5. Bassat Q, Watkins K, Peterson S, Bijleveld P, Detjen A, Winn J, et al. Global forum on childhood pneumonia steering committee. The first Global Pneumonia Forum: recommendations in the time of coronavirus. *Lancet Glob Health.* (2020) 8:e762–e3. doi: 10.1016/S2214-109X(20)30125-X
6. Wilkes MS, Conrad PA, Winer JN. One health-one education: medical and veterinary inter-professional training. *J Vet Med Educ.* (2019) 46:14–20. doi: 10.3138/jvme.1116-171r
7. Hu B, Guo H, Zhou P, Shi ZL. Characteristics of SARS-CoV-2 and COVID-19. *Nat Rev Microbiol.* (2020) 19:141–54. doi: 10.1038/s41579-020-00459-7
8. Coccia M. Factors determining the diffusion of COVID-19 and suggested strategy to prevent future accelerated viral infectivity similar to COVID. *Sci Total Environ.* (2020) 10:138474. doi: 10.1016/j.scitotenv.2020.138474
9. Figueroa D, Duprat X. Remedying anthropogenic zoonoses. *Anim Sentience.* (2020) 30:1–3. doi: 10.51291/2377-7478.1666
10. Lucey DR, Sholts S, Donaldson H, White J, Mitchell SR. One health education for future physicians in the pan-epidemic "Age of Humans". *Int J Infect Dis.* (2017) 64:1–3. doi: 10.1016/j.ijid.2017.08.007
11. Cianfagna M, Bolon I, Babo Martins S, Mumford E, Romanelli C, Deem SL, et al. Biodiversity and human health interlinkages in higher education offerings: a first global overview. *Front Public Health.* (2021) 9:124. doi: 10.3389/fpubh.2021.637901
12. Prokop P, Fancovicová J, Krajcovicová A. Alternative conceptions about micro- organisms are influenced by experiences with disease in children. *J Biol Educ.* (2016) 50:61–72. doi: 10.1080/00219266.2014.1002521
13. Haxton E, Lindberg A, Troell K, Redican KJ. One Health education meets science. *Infect Ecol Epidemiol.* (2015) 5:30264. doi: 10.3402/iee.v5.30264
14. Carrascosa Alís J, Gil Pérez D, Valdés Castro P. El problema de las concepciones alternativas, hoy. *Didáctica de las Ciencias Experimentales y Sociales.* N° 18. (2005). p. 41–63. Available online at: https://core.ac.uk/reader/71014450
15. Neulight N, Kafai YB, Kao L, Foley B, Galas C. Children's participation in a virtual epidemic in the science classroom: making connections to natural infectious diseases. *J Sci Educ Technol.* (2007) 16:47. doi: 10.1007/s10956-006-9029-z
16. Driver R. *Dando Sentido a la Ciencia en Secundaria: Investigaciones Sobre las Ideas de los Niños.* New York, NY: RoutledgeFalmer (1999). 272 p.
17. JUNAEB Junta Nacional de Auxilio Escolar y Becas. *Prioridades 2018 con IVE SINAE Básica Media y Comunal.* (2018). Available online at: https://www.junaeb.cl/ive. (accessed March 15, 2019).
18. de Oliveira LH, Shioda K, Valenzuela MT, Janusz CB, Rearte A, Sbarra AN, et al. Multinational study for PCV impact in Mortality Study Team. Declines in pneumonia mortality following the introduction of pneumococcal conjugate vaccines in Latin American and Caribbean countries. *Clin Infect Dis.* (2020) 73:306–13. doi: 10.1093/cid/ciaa614
19. Johnson NF, Velásquez N, Restrepo NJ, Leahy R, Gabriel N, Oud SE, et al. The online competition between pro- and anti-vaccination views. *Nature.* (2020) 582:230–3. doi: 10.1038/s41586-020-2281-1
20. Educación. 2020 *Cuánto ha Avanzado la Educación Chilena en la Última Década? Y Cuánto nos Falta Para Llegar a la "Meta".* (2017). Available online at: http://www.educacion2020.cl/sites/default/files/estudio_ed._chilena_2008-2018.pdf (accessed December 11, 2020).
21. Educación. *2020 Plan Nacional: la Educación Chilena al 2030.* (2017). Available online at: http://www.educacion2020.cl/sites/default/files/plan_nacional_capitulo_1.pdf (accessed December 12, 2020).
22. OCDE. *Marco de Evaluación y de Análisis de PISA para el Desarrollo: Lectura, matemáticas y ciencias. Versión Preliminar.* París: OECD Publishing (2017).
23. Bahamonde N. Pensar la educación en biología en los nuevos escenarios sociales: la sinergia entre la modelización, naturaleza de la ciencia, asuntos socio-científicos y multirreferencialidad. *Rev Bio-grafía Escritos Sobre Biol Enseñanza.* (2014) 7:87–98. doi: 10.17227/20271034.13biografia87.98
24. Hopkins J. *COVID-19 Map - Johns Hopkins Coronavirus Resource Center.* (2020). Available online at: https://coronavirus.jhu.edu/map.html (accessed December 13, 2020).
25. Nyatanyi T, Wilkes M, McDermott H, Nzietchueng S, Gafarasi I, Mudakikwa A, et al. Implementing One Health as an integrated approach to health in Rwanda. *BMJ Glob Health.* (2017) 2:e000121. doi: 10.1136/bmjgh-2016-000121
26. Lebov J, Grieger K, Womack D, Zaccaro D, Whitehead N, Kowalcyk B, et al. A framework for One Health research. *One Health.* (2017) 3:44–50. doi: 10.1016/j.onehlt.2017.03.004
27. Chomel BB. Emerging bacterial zoonoses. In: *Conference Presented on the University of Nihon, Japan, 29 de Agosto de 2000 and the University of Rakuno Gakuen.* Hokkaido (2000).
28. Berrian AM, Smith MH, van Rooyen J, Martínez-López B, Plank MN, Smith WA, et al. A community-based One Health education program for disease risk mitigation at the human-animal interface. *One Health.* (2018) 5:9–20. doi: 10.1016/j.onehlt.2017.11.002
29. Alarcón A, Lagos I, Fica A. Gastos hospitalarios por neumonía neumocóccica invasora en adultos en un hospital general en Chile. *Rev Chilena Infectol.* (2016) 33:389–94. doi: 10.4067/S0716-10182016000400003
30. Ilabaca I, Olaeta I, Campos E, Villaire J, Tellez-Rojo MM, Romieu I. Association between levels of fine particulate and emergency visits for pneumonia and other respiratory illnesses among children in Santiago, Chile. *J Air Waste Manag Assoc.* (1999) 49:154–63. doi: 10.1080/10473289.1999.10463879
31. Suen LKP, So ZYY, Yeung SKW, Lo KYK, Lam SC. Epidemiological investigation on hand hygiene knowledge and behaviour: a cross sectional study on gender disparity. *BMC Public Health.* (2019) 19:401. doi: 10.1186/s12889-019-6705-5

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The handling editor is currently organizing a Research Topic with one of the authors DF.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Frontiers in
Public Health

Explores and addresses today's fast-moving healthcare challenges

One of the most cited journals in its field, which promotes discussion around inter-sectoral public health challenges spanning health promotion to climate change, transportation, environmental change and even species diversity.

Discover the latest Research Topics

See more →

Frontiers

Avenue du Tribunal-Fédéral 34
1005 Lausanne, Switzerland
frontiersin.org

Contact us

+41 (0)21 510 17 00
frontiersin.org/about/contact