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A tool for rapid assessment of wildlife markets in the Asia-Pacific Region for risk of future zoonotic disease outbreaks

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ABSTRACT

Decades of warnings that the trade and consumption of wildlife could result in serious zoonotic pandemics have gone largely unheeded. Now the world is ravaged by COVID-19, with tremendous loss of life, economic and societal disruption, and dire predictions of more destructive and frequent pandemics. There are now calls to tightly regulate and even enact complete wildlife trade bans, while others call for more nuanced approaches since many rural communities rely on wildlife for sustenance. Given pressures from political and societal drivers and resource limitations to enforcing bans, increased regulation is a more likely outcome rather than broad bans. But imposition of tight regulations will require monitoring and assessing trade situations for zoonotic risks. We present a tool for relevant stakeholders, including government authorities in the public health and wildlife sectors, to assess wildlife trade situations for risks of potentially serious zoonoses in order to inform policies to tightly regulate and control the trade, much of which is illegal in most countries. The tool is based on available knowledge of different wildlife taxa traded in the Asia-Pacific Region and known to carry highly virulent and transmissible viruses combined with relative risks associated with different broad categories of market types and trade chains.

1. Introduction

A growing body of evidence linking wildlife trade and consumption to zoonotic events has prompted conservationists, epidemiologists, and virologists to issue warnings of zoonotic disease outbreaks with pandemic potential if such practices are not halted [1–11]. These warnings have gone largely unheeded. Now, with the COVID-19 pandemic adversely affecting every country in the world, there are renewed calls for urgent controls and even outright bans of the wildlife trade [8,12]. China, arguably the biggest wildlife consuming and trading nation, imposed a broad ban on wildlife trade and markets [13]. However, there is also opposition to wildlife trade bans from several quarters, citing restrictions on livelihood opportunities and reduced access to food for local communities who depend on wildlife, and concerns that trade will be driven underground [14–18].

While almost all wildlife trade has some level of zoonotic risks, some taxonomic groups (e.g., primates, bats, pangolins, civets, and rodents) are high-risk reservoirs of more virulent pathogens. Thus, the trade should be tightly regulated and monitored to prevent the sales of such high-risk species [4]. Particular types of wildlife markets and trade chains can also increase risk of disease transmission and spread based on: 1) the numbers and types of wildlife taxa being traded, especially the diversity of animals for sale; 2) interactions between wildlife, people, domestic, or peridomestic species; 3) length of prior and posterior trade chains; 4) connectedness of the market within the network of markets; 5) stressors on animals in markets; and 6) movement patterns of buyers and traders beyond points of sale [19]. Because even rare zoonotic events associated with the wildlife trade can have catastrophic socio-economic consequences, strategic wildlife trade prohibitions are important to reduce the probability of future trade-related pandemics. But given the opposition to wildlife trade bans, it is more likely that more nuanced approaches will emerge that balance market risk levels with subsistence hunting and use of wildlife by rural people [20,21].

We present a tool (Appendix A) to assess wildlife markets in the Asia-

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Pacific region for future risks of zoonotic outbreaks based on the types of disease-risk taxa sold and different trade situations. The tool can guide the region's governments, especially the public health and wildlife sector authorities, to assess the relative risks of serious emerging infectious diseases associated with wildlife trade and inform development of appropriate policies and regulations to control the wildlife trade. The tool can also be used by other stakeholders, including non-governmental and community-based organizations, to monitor markets for risks associated with wildlife trade.

2. Methods

The tool is based on available knowledge of different wildlife taxa that are: 1) sourced and traded in the Asia-Pacific Region and known to be reservoirs of highly virulent, transmissible viruses; and 2) market types and trade chains. Descriptions about the tool and embedded formulae are presented in Appendix B.

Zoonotic and wildlife-trade science is an evolving field. With accumulating knowledge about viruses and other pathogens, primary and intermediate wildlife hosts [22], insights into the role of wildlife trade chains in zoonoses will also improve and can be used to adjust the parameters in the tool. In the meantime, because of the urgency to assess wildlife markets and prevent another pandemic, this tool can be used invoking the precautionary principle.

2.1. Market trade risk

We identified 11 generalized trade situations in the Asia-Pacific region (Table 1) and assessed them for risk using three variables: Transmission Risk (TR), Spread Potential (SP), and Zoonotic Virus Risk (ZVR) (see Appendices A, B). These variables adequately classify risks of potential zoonoses based on market size, crowding of wildlife that creates stressful situations, hygiene conditions, number and turnover of people through the market, distance buyers may travel after visiting a market, and points along market trade chains that could allow viruses to accumulate and amplify the potential for zoonoses.

Each market type was given a qualitative score from 1 to 10, representing the combined contributions of the three variables (Appendix A). Because of the importance to clearly convey the level of uncertainty when assigning relative risk attributes to different features or processes in a wildlife trade chain, we applied levels of uncertainty to our estimates of TR, SP, and VZR through independent scoring of the variables by regional experts. The scores were used to obtain a combined 'Market Risk' score where <1 = Very Low Risk; 1–2 = Low Risk; 3–5 = Medium Risk; 6–8 = High Risk; and 9–10 = Very High Risk (Appendices A, B).

Improvements in trade hygiene, regulation, sale, and butchering practices could diminish risk to some extent, but the socio-economic and health consequences of zoonotic disease pandemics associated with trading in high disease-risk wildlife argues for a broader set of actions—no matter how clean the cages and knives are, dangerous viruses can spillover to humans in trade chains that include high disease-risk taxa.

Table 1
General types of Asia-Pacific wildlife sale markets or points of sale.

Description of Wildlife Trade Sale/Trade Chain Type	Generalized Type Name
Larger, permanent markets in cities (consumption, pets, parts) (locally wild caught, possibly transported over distance or international, or captive bred, alive and dead)	Permanent wildlife markets
Wildlife sales from restaurants	Restaurant sales
Wildlife sales retrieved from warehouse on demand	Warehouse sales
Wildlife sales from TCM stalls (usually dead, dried, frozen)	TCM stalls
Wildlife sales from online or offline ads – shipped or picked up or delivered	Online trade delivery
Roadside sale of recently caught wildlife	Roadside sales
Rural (village) bushmeat markets (locally-caught or transported within region – live, dead, smoked, regular markets)	Rural bushmeat markets
Urban (town) bushmeat markets (domestic markets, town markets, caught in region, shorter transport)	Urban (town) bushmeat markets
Research animal facilities	Research facility
Local village sales/trade/barter & one-off sale from vehicles/boats of freshly caught wildlife	Local village sales/trade/barter
Wildlife farms	Wildlife farms

2.2. High disease-risk taxa

The assessment and scoring of taxonomic groups commonly traded in the Asia-Pacific region for hosting zoonotic viruses with epidemic or pandemic potential [19] and the risk categorizations of the taxonomic groups are presented in Table 2 (details in Appendix A). Some taxonomic groups, such as rodents, are highly diverse, and the group could include species that are of lower risk than others [23]. However, given the severity of economic, health, and social costs and consequences of epidemics and pandemics, and current knowledge gaps about pathogen host species [24–26], we employ a precautionary principle and consider entire taxonomic groups to be high disease risk until more information is available. We hope that such an approach will encourage and catalyze epidemiological and zoonoses research to de-list or up-list species as relevant and appropriate. As the status of species changes, the model can be adjusted. We use simple, transparent, Boolean logic formulae to enable these adjustments.

2.3. Evaluating risk of specific markets or points of sale: traded taxa risk

The Taxonomic Risk categories are combined with a qualitative index based on numbers of individuals from the respective taxonomic categories found in a market—the premise being that numbers of individuals can amplify pathogen prevalence and risk of transmission (Appendices A, B). However, even small numbers of high disease-risk taxa can pose greater risks of transmission and spillover. For example,

Table 2
Taxonomic Risk categories of key faunal groups. Criteria for categorizations and references are provided in Supplementary Material Appendix A.

Taxonomic Group	Taxonomic Risk Category
Primates-Great Apes (Orangutan, Gibbons)	High
Pteropodidae - fruit bats/flying foxes	High
Rhinolophidae - horseshoe bats	High
Sciurognathi - mice, rats, hamsters, jerboas, voles, others	High
Manidae - pangolins	High
Viverridae - civets, mongooses	High
Primates - monkeys, macaque, loris, tarsier, other non-great ape	High
Wild birds - notably waterbirds	High
Mustelidae - weasels, otter, badgers, hog badgers, polecats, marten	High
Sciuridae - squirrels	Medium
Suidae - wild pigs, babirusa	Medium
Cervidae, Moschidae, Tragulidae other deer-like Artiodactyla	Medium
Felidae - wild cats	Medium
Canidae - wild dogs, jackals, foxes, wolves,	Medium
Perissodactyla - tapir, rhinoceros, asses, horses	Medium
Ailuridae - red panda	Medium
Ursidae - bears	Medium
Hystricidae - porcupines	Medium
Tupaidae - tree shrews	Low
Elephantidae	Low
Dermoptera - colugo	Low
Leporidae - hares	Low
Reptiles	Low
Amphibians	Low
Fishes	Low
Invertebrates	Low

bats are known to carry many serious pathogens [27–30]. Thus, even a small number (1–3) of Pteropid bats in a market should pose at least a medium risk.

When using the tool, the numbers of wild animals for sale in a specific market should be estimated—or counted, if few—and the data entered in the relevant column (Appendix B). These numbers are converted into qualitative threat categories. Information on traded taxa and numbers of animals of each taxon can be derived from snapshot surveys, estimates from several site visits, or based on expert assessments. The estimates can include live and dead animals and even parts if they can be used to estimate numbers with some reliability (e.g., numbers of heads). Finally, the Taxonomic Risk category and Number-based Category are combined for a Cumulative Risk Factor using the matrix shown in Fig. 1.

2.4. Combining market and taxon risks

Market and taxon risk assessments are combined in a risk matrix of traded taxa (Y axis) and markets (X axis) (Appendix A; Fig. 2) that provide an assessment of disease risk associated with specific wildlife markets. Risk levels for a given location may vary over time as different combinations and numbers of taxa are traded and the tool can be used to monitor these changes, including from better regulation of markets for high disease-risk taxa.

2.5. Ecohealth and wildlife trade

Loss, fragmentation, and degradation of tropical forests are significant drivers of emerging infectious diseases [31–35]. Forest clearing and settlement exposes loggers, hunters, and settlers to novel zoonotic pathogens [4]. Wildlife sourced for the commercial trade can also introduce novel pathogens further afield [3,4,36]. The decline or loss of some species, especially top predators, degrades ecosystems and creates conditions that elevate risks of zoonotic events, albeit indirectly [4,37]. Therefore, the trade in wildlife species that play important roles in structuring ecosystems and maintains ecosystem diversity and health should also be prohibited and we have included these taxa such as Felidae and Canidae in the list of taxa to be assessed for market risk.

2.6. Testing the tool

We tested the tool using survey data from 36 wildlife markets in *Lao* PDR collected by Greatorex et al. [19]. These included permanent wildlife markets in larger cities ($N = 5$), wildlife markets in smaller towns ($N = 12$) and villages ($N = 10$), and roadside stalls ($N = 9$). We also used recent data from 10 wildlife markets in Laos and eight sales from northern Myanmar (Table 3, Appendix C).

3. Results

For the Greatorex et al. [19] data analysis, each market type had days where disease risk was estimated as very low risk (VLR), low risk (LR), high risk (HR), and very high risk (VHR) (Table 3). The smaller town markets consistently had VHR days with little variation, likely because the markets are concentration points for high disease-risk taxa brought in from surrounding villages. Markets in larger urban centers generally had MR levels or above, with some consistently estimated as VHR, driven, in part, by high numbers of bats, wild birds, rodents, viverids, and other high disease-risk taxa.

The risk levels of village markets and roadside sales showed considerable daily variation, depending on the presence or absence of high disease-risk taxa. These markets often had high disease-risk species, such as bats, not commonly seen in the larger urban markets. The taxa for sale on any given day in these markets depended on what hunters bring in. Thus, one day there may be only squirrels and another day bats and civets causing disease risk to shift from LR to VHR. A precautionary approach would argue that disease risk levels for markets should be assessed based on the highest risk levels, and these rural markets regularly had VHR days. Some village markets, however, were consistently VLR, perhaps due to wildlife depletion in the surrounding areas.

In Myanmar, the single warehouse sale (a trader's house) was VHR because of the presence of langur and pangolin, while the restaurant sales at two venues were MR and VLR, and a town market was VLR because only reptiles were observed for sale on that day. Of the four roadside stall sites, three were VLR and one was HR. Some markets predominately had dried animal parts, but these included endangered species, such as tiger, gaur, elephant skin, or ivory. While the trade in these species is illegal and they are very high conservation value species, the risk from zoonosis was low.

	Taxa Risk			
Market Risk	**High Risk**	**Medium Risk**	**Low Risk**	**Lowest risk**
High Risk	Very High Risk	High Risk	Medium Risk	
Medium Risk	High Risk	Medium Risk	Low Risk	Low Risk
Low risk		Medium Risk	Low risk	Lowest Risk

Fig. 1. Matrix of taxon risk categories used to derive the Cumulative Risk Factor.

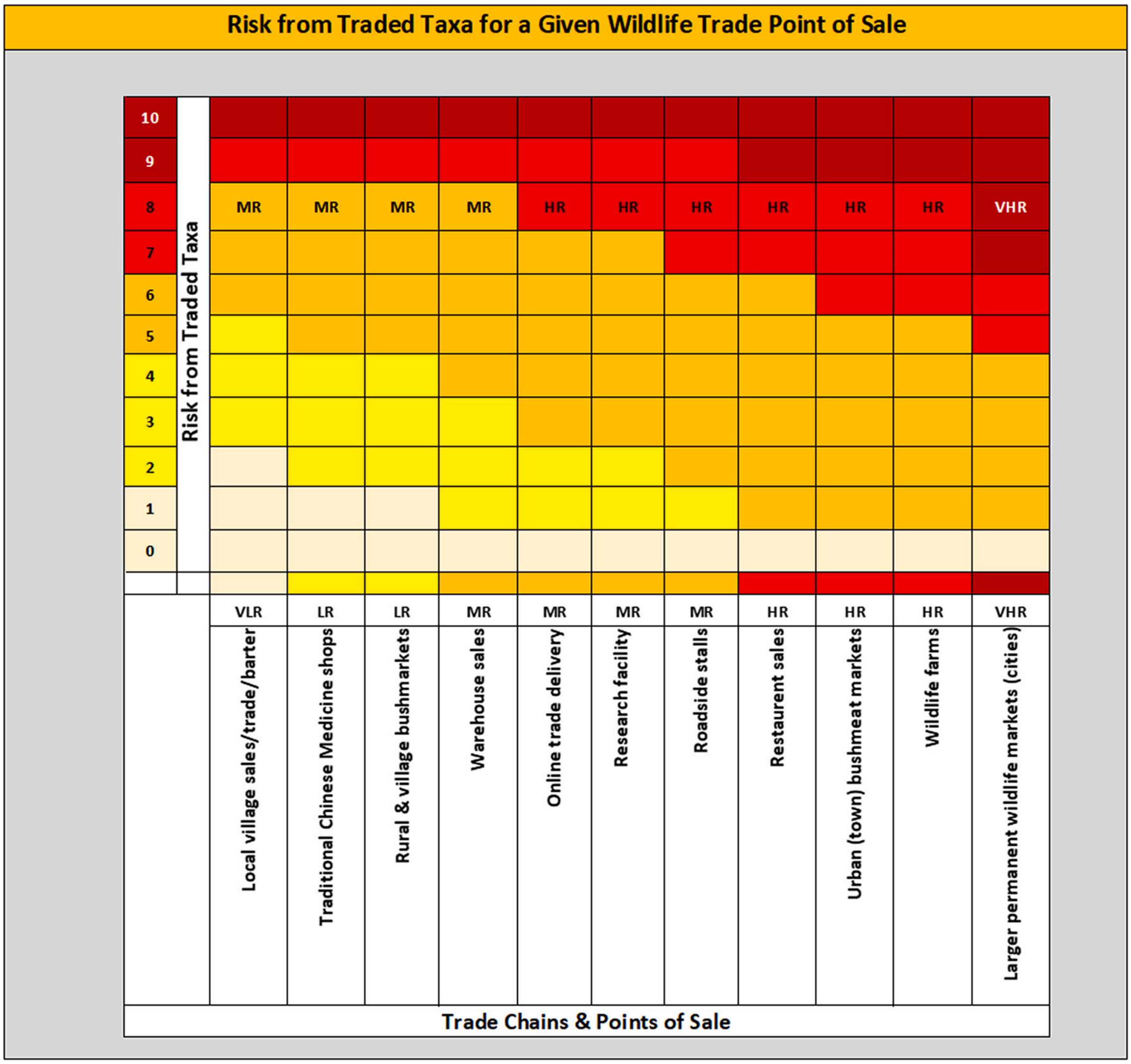

Fig. 2. Graphic presentation of risks from traded taxa and trade chains (supplementary material Appendix A). The risk levels are colour-coded for easy reference; Very Low Risk (VLR) as beige cells, Low Risk (LR) as yellow cells, Medium Risk (MR) as orange cells, High Risk (HR) as red cells, and Very High Risk (VHR) in dark red. In this example, we entered 3 Pteropodidae (fruit bats or flying fox bats), 20 Sciuridae (squirrels), and 5 Cervidae (deer) as a hypothetical market survey into the tool. The results indicate that the village and rural markets are classified as Medium Risk (MR), whereas the trade situations further along the trade chain are classified as being High Risk (HR) and large urban markets are classified as being Very High Risk (VHR) for the presence of these taxonomic groups and numbers. The classification is especially driven by the presence of bats, which are in the very high-risk category. The market situations further along the trade chains could allow pathogens to accumulate and amplify, presenting High Risk (HR) situations, while the Very High Risk (VHR) levels in the large urban markets are driven by the high density and turnover of people visiting these markets, with greater probability of mixing wildlife and other animals under stressful situations. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Some clear trends from the test of the tool are that smaller town markets consistently have very high disease risks. Village and roadside sale venues regularly presented high disease risk situations. For all market types, there were high disease risk situations depending on the numbers of the taxa being traded that day. Thus, for wildlife trade situations in Southeast Asia there are regular very high to high disease risk situations, indicating that almost all unregulated wildlife trade has a disease risk level that requires tight regulation and monitoring.

4. Discussion

4.1. COVID-19 response: calls for bans and systemic policies

The COVID-19 pandemic has elicited serious reevaluations of the consequences of the wildlife trade. China imposed broad bans of terrestrial vertebrate wildlife markets and consumption [21]. Vietnam, another significant market for consumption and a conduit for wildlife to China, followed suit with tightening laws pertaining to trade and consumption of wildlife [20], but stopped short of a ban [38]. The effectiveness of these actions, however, remains uncertain. There are anecdotal reports of some wildlife markets reopening or continuing to operate in China and monitoring the vast numbers of markets can be challenging for authorities. Much of the wildlife traded and consumed in China is sourced from other countries in Asia through trade chains. Thus, neighbouring countries should also take steps to prohibit or tightly regulate the wildlife trade and monitor markets from rural sources through to urban markets and along the international trade chains for high disease-risk wildlife.

The trends from market data in Laos and Myanmar—two regional source countries for China, but also consumption countries—indicate that even small, rural markets and roadside sale venues rank high for disease risk. Millions of people in Asia still practice subsistence hunting for local consumption and trade [39]. However, regulations that permit such practices should be evaluated with the knowledge that wildlife that

Table 3
Test of wildlife trade disease risk tool using field data from wildlife sale venues in Laos from Greatorex et al. [19], WWF Laos (2021) and Myanmar (WWF Myanmar 2019–2020). Numbers indicate individual markets, grouped under market types and venues. Multiple entries for an individual market are risk assessment from different survey dates. Very High Risk = VHR; High Risk = HR; Medium Risk = MR; Low Risk = LR; Very Low Risk = VLR.

Large City Market	Town Market	Rural/Village Market	Roadside Sale	Ware-house	Restaurant
Laos (Greatorex et al. 2016 data)					
1. (VHR VHR VHR), 2. (VHR), 3. (VHR) 4. (HR) 5. (MR MR MR MR)	6. (VHR VHR VHR), 7. (VHR VHR VHR), 8. (VHR VHR VHR), 9. (VHR VHR), 10. (VHR VHR), 11. (VHR VHR), 12. (VHR LR), 13. (VHR), 14. (VHR), 15. (VHR), 16. (LR) 17. (VLR)	18. (VHR VHR VHR VHR VHR VHR MR LR) 19. (VHR VHR HR VLR) 20. (VHR HR LR VLR) 21. (VHR MR VLR) 22. (VHR) 23. (VHR) 24. (VHR) 25. (MR VLR VLR) 26. (VLR VLR VLR) 27. (VLR)	28. (VHR VHR MR) 29. (VHR LR LR) 30. (VHR) 31. (VHR) 32. (VHR) 33. (LR LR LR LR) 34. (LR LR) 35. (LR) 36. (LR)		
Laos (data from WWF Laos 2021)					
	1. (VHR HR), 2. (MR MR), 3. (MR VLR), 4. (VLR VLR VLR)	5. (LR LR), 6. (VLR VLR), 7. (VLR VLR)	8. (LR LR) 9. (LR LR) 10. (VLR VLR)		
Myanmar (data from WWF Myanmar 2019–2020)					
	1. (VLR)	4	2. (HR) 3. (VLR) 4. (VLR) 5. (VLR)	6. (VHR)	7. (MR) 8. (VLR)

enters complex trade chains often ends up in crowded, urban markets.

Pandemics from emerging zoonotic pathogens are expected to become more frequent if current rates of wildlife exploitation, forest encroachment, and environmental degradation continue [31,40]. Thus, there is an urgent need for systemic policies on wildlife trade, informed by science, to prevent such outcomes [36]. Our tool can help to assess wildlife trade situations, from village trade stalls to urban markets for zoonosis risk, inform policy, and enable monitoring of markets for relative zoonotic risks. Public health authorities can then make decisions on whether to prohibit or permit trade depending on the types and numbers of taxa being sold in these market situations. Because the tool provides relative risk levels along various market types that could be links along a trade chain, health and enforcement authorities can also identify strategic points along the trade chain where relevant actions can be taken for effective outcomes. For instance, if large urban markets are being supplied with high zoonotic disease-risk taxa, such as primates or bats, from rural markets, it may be more strategic to close the rural markets that sell these species or work with local communities to apprise them of the risks of hunting and trading in these species.

Even at national scales, prohibitions and tighter regulations in wildlife markets would call for close monitoring of markets, including where some trade of low disease-risk wildlife would be permitted. However, it is unlikely that governments would have adequate resources to monitor all markets, especially in rural areas [21]. Thus, it is important that market monitoring engages non-governmental stakeholders, including from the public [21]. These monitors should have ready access to information and a practical tool that is easy to use yet provides a robust assessment of the market conditions to detect and report illegal cases. The tool we present here meets these criteria. We acknowledge that it can be improved and refined, but such improvement can evolve from its use. The growing recognition of risk levels in other types of trade situations, such as wildlife farming and exotic pet markets, may require further adjustments to the tool.

4.2. *One Health approach for a holistic strategy*

One Health is a multisectoral, transdisciplinary approach to health that recognizes the inter-connectedness between people, nature, and their shared environment, and ecosystem health is a core component of the approach [36,41–43]. The tool links ecological health with public health in accordance with the One Health concept.

Forest fragmentation, degradation, and loss have been associated with emerging infectious zoonoses with potential to cause epidemics and pandemics [3,4,31,34,36,43,44]. Hunting for local consumption has been a long-time practice among rural communities that live in and around the forests. But recently, the practice has intensified and shifted to supply market demands, creating 'empty forests' across Southeast Asia, bereft of wildlife because of intense hunting pressure [e.g., [45]].

Small rural markets may have few wildlife in stock, but they could be the sources for larger markets downstream along wildlife trade chains, especially as roads facilitate access for commercial buyers into remote, rural areas. These purchases may then be consolidated along the trade chains, increasing zoonotic risk. Moreover, thousands of small markets can contribute to ecological degradation of forests, especially if the markets are sourcing ecologically important species, such as primates, bats, felids, canids, and some Perrisodactlya. Thus, rural markets that carry even small numbers of these species should qualify as medium to very high risk. For example, in our classification, even one great ape in a rural market qualifies it as very high risk.

As ecological communities are degraded with the removal of predators, populations of high disease-risk species can rise due to ecological release, increasing the risk of dangerous zoonotic events [46–48]. Most wild felid and canid populations in Asia's forests are in decline because of hunting pressure, and prey and habitat loss. Because of the ecological role of predators in controlling populations of higher disease-risk prey taxa, we rationalize that even small numbers of wild felids and canids in markets should be adequate thresholds for the markets to be considered as at least of Medium Risk to capture the eventual ecological and epidemiological fallout from removing the predators from the ecosystems [37]. While these taxa do not carry as many zoonotic-potential viruses compared with higher disease-risk taxa such as rodents, they do carry some high-risk viruses (Appendix A) and can be infected by SARS-CoV-2 [49,50].

5. Conclusions

We present this tool to assess various wildlife markets and trade chains for potential zoonotic disease emergence events and to, thereby, inform policy decisions aimed at regulating or closing them based on objective analyses. Overall, the tool was able to discriminate variation among market types, localities, and risks on different days based on our testing with field data and can be used to guide decision-making by health and wildlife authorities.

We have kept the tool simple and transparent so it can be used by a range of stakeholders. We acknowledge that it is not perfect, but it is based on the best available knowledge currently, with transparent assumptions. We have provided access to the formulae used to assess risks so they can be refined as new information becomes available and adjusted to various regional, national, or market contexts. With predictions that human activities are setting the stage for more serious pandemic-proportion zoonotic spillover events [23,24], this tool is timely for decision-making using precautionary principles. We hope it will also catalyze necessary research to close knowledge gaps for improvement.

Author statement

All authors contributed equally to conceptualization, methodology and analysis, writing and revision.

Declaration of Competing Interest

The authors declare that they have no conflicts of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.onehlt.2021.100279.

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