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IDRISI Taiga
Guide to GIS and Image Processing

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The Land Change Modeler for Ecological Sustainability

Introduction

The Land Change Modeler (LCM) for Ecological Sustainability is an integrated software environment for Commissioned by the Andes Center for Biodiversity Conservation of Conservation International (our inspiration for the *Andes Edition* name), LCM is the first extensive vertical application developed by Clark Labs. (IDRISI is a horizontal application – a software product meant to fulfill many applications. In contrast, a vertical application is directed towards a specific application.) The Land Change Modeler for Ecological Sustainability is oriented to the pressing problem of accelerated land conversion and the very specific analytical needs of biodiversity conservation.

Hate to Read the Documentation? A Power-User Alternative

Experienced users of GIS can probably figure out most of what LCM does on their own. However, there are some critical issues that expert and novice users alike need to know. Look for and pay careful attention to special sections titled "*Critical Things to Kno*w!"

Critical Things to Know about LCM in General

1. The current version of LCM is experimental and intended for evaluation and comment only. Most of the procedures incorporated are new and have not been widely tested. As a result, we offer these tools in the spirit of scientific exploration and invite constructive commentaries about how they can be extended or improved.

2. Change analysis and prediction in LCM are organized around transition sub-models. A transition sub-model can consist of a single landcover transition or a group of transitions that are thought to have the same underlying driver variables.

3. All selected transition sub-models must be modeled before change prediction can be undertaken.

4. LCM incorporates the option of dynamic landcover variables and dynamic road development.

5. All files used by LCM must be contained within the Working Folder or one of the project Resource Folders. DO NOT USE THE BROWSE BUTTON to select files.

Accessing LCM and its Functions: Recommendations

LCM is accessed from the Modeling menu and opens as a special dialog attached to the left-hand side of IDRISI's workspace. It is generally recommended that serious users of this application consider the use of an Ultra-Wide XGA (1920 x 1200) screen or a dual-monitor setup. However, for users with lower resolution devices, LCM can be minimized to the left margin by clicking on the "-" symbol on its banner (and similarly, the "+" symbol to re-expand it).

Tabs and Panels

LCM is organized around a set of five major task areas expressed as tabs for:

Analyzing past landcover change

Modeling the potential for land transitions

Predicting the course of change into the future

Assessing its implications for biodiversity, and

Evaluating planning interventions for maintaining ecological sustainability.

Within each tab, a series of tasks/analytical stages are presented as a series of drop-down panels. You can have as many drop-down panels open as you wish – they are presented this way simply to accommodate varying screen resolutions.

The first three of the five tabs of LCM are intended for the integrated analysis of landcover change and its projection into the future. As a result access to almost all panels on these tabs requires the specification of a minimal set of project parameters located on the first panel of the first tab.

Note that the panels on the first three tabs are generally organized around a sequential set of operations that should be followed one after the other.

A Recommendation

We *strongly* recommend that you complete the tutorial exercises for LCM. This is the fastest way of learning the full scope of the system.

The Change Analysis Tab

The Change Analysis tab provides a set of tools for the rapid assessment of change, allowing one to generate one-click evaluations of gains and losses, net change, persistence and specific transitions both in map and graphical form.

Critical Things to Know!

1. The LCM Project Parameters panel must be filled out (with the exception of the palette, optional elevation model and basis roads layer) before the majority of the panels on the first three tabs become active. landcover maps *must* use 0 for background areas and should normally contain the year date (2 or 4 digit) as part of their name.

2. The Ignore Transitions checkbox on the Change Maps panel provides an important means of ignoring small and insignificant transitions and affects not only the change maps produced, but also the default transition sub-models that appear in the Transition Potentials tab.

3. The project name specified is used as a prefix for a range of important operational files. DO NOT DELETE any files that begin with the project name prefix.

The LCM Project Parameters Panel

This panel allows you to specify the essential files associated with the landcover change analysis of a specific study area, as well as a project name and (optionally) a preferred landcover palette. Note that some aspects of LCM can be used without specifying these files, most notably the species modeling and biodiversity modeling tools on the Implications tab. However, they are required for most elements of LCM.

For the change and prediction analyses, a minimum requirement is the specification of two landcover maps that can be used as the basis of understanding the nature of change in the study region and the means of establishing samples of transitions that should be modeled. Optional inputs include an elevation model and basis roads layer that are used in dynamic road development.

Notes

1. The landcover maps must be byte or integer images with identical legends.

2. Background areas must be coded with 0 and must be identical on both maps.

The Change Analysis Panel

The Change Analysis panel provides a rapid quantitative assessment of change by graphing gains and losses by landcover category. A second option, net change, shows the result of taking the earlier landcover areas, adding the gains and then subtracting the losses. The third option is to examine the contributions to changes experienced by a single landcover.

Notes

1. Changing the units on this panel causes the units on the Change Maps panel to also change.

The Change Maps Panel

This panel provides the ability to create a variety of change maps.

Notes

1. The Ignore Transitions checkbox is *very* important – please read the entire text of this note. This checkbox is used to filter out minor transitions that may be the result of map errors or may be considered to be insignificant for the purpose of the study. This checkbox affects not only the maps produced from this panel, but also the transitions that are automatically included for analysis on the Transition Potentials tab. This is the quickest and most effective way of narrowing down the transitions to those that are essential for understanding and modeling change.

2. Specifying an output name is optional. If one is not specified, a temporary filename is used.

3. The Map Exchanges option is designed for the examination of exchanges such as those between agriculture and secondary forest in areas of swidden agriculture.

4. Changing the measurement units on this panel also changes the units on the Change Analysis panel.

5. Note that an All option is provided in the drop-down lists of landcover categories. Thus choosing to map the changes from All to a specific category maps any change that ended up in the designated category, differentiated by the start category.

The Spatial Trend of Change Panel

In landscapes dominated by human intervention, patterns of change can be complex, and thus very difficult to decipher. To facilitate interpretation in these contexts, a spatial trend analysis tool has been provided. This is a best fit polynomial trend surface to the pattern of change. The default is a 3rd order surface which is good for a very broad overview. Trends up to 9th order can be calculated. However, note that the time needed to calculate the surface increases substantially as the order is increased.

Notes

1. The intention of this module is to provide a means of generalizing about the pattern of change. The numeric values do not have any special significance. The surface is created by coding areas of change with 1 and areas of no change with 0 and treating them as if they were quantitative values.

2. The analytical work done by this option is achieved by a call to the TREND module. For details on how it works, please refer to the on-line Help System for TREND.

The Transition Potentials Tab

The Transition Potentials tab allows one to group transitions into a set of sub-models and to explore the potential power of explanatory variables. Variables can be added to the model either as static or dynamic components. Static variables express aspects of basic suitability for the transition under consideration, and are unchanging over time. Dynamic variables are time-dependent drivers such as proximity to existing development or infrastructure and are recalculated over time during the course of a prediction.

Once model variables have been selected, each transition is modeled using either Logistic Regression or IDRISI's extensively enhanced Multi-Layer Perceptron (MLP) neural network. After a detailed assessment of empirical modeling tools (such as Weights-of-Evidence, Empirical Probabilities, Empirical Likelihoods, etc.), it was found that these two approaches offer the strongest capabilities, particularly the MLP. The MLP neural network has been extensively enhanced to offer an automatic mode that requires no user intervention. The result in either case is a transition potential map for each transition – an expression of time-specific potential for change.

Critical Things to Know!

1. Change prediction in LCM is based on a series of empirically evaluated sub-models.

2. By default, each transition is considered to be a separate sub-model, but multiple transitions can be grouped into a single sub-model if it is considered that they all result from the same underlying driving forces. To group transitions into a higher-order sub-model, simply assign them the same sub-model name. Note that this option is only available if the multi-layer perceptron modeling option is used.

3. The Sub-Model to be Evaluated drop-down combo box is what determines which transition will be modeled from the Run Transition Sub-Model panel.

4. In general, the multi-layer perceptron performs the best in modeling transitions. Note that for both options, categorical variables must either be converted into a set of Boolean (dummy) variables, or transformed using the Evidence Likelihood transformation option (highly recommended).

The Transition Sub-Models: Status Panel

The table on this panel lists all transitions that exist between the two landcover maps. The *included* field will be listed as *No* for any transitions that were filtered out using an area threshold on the Change Analysis tab. You can reinstate any transition that has been excluded by clicking onto the *included* field entry, which will cause it to change to *Yes*. Similarly you can deselect any included transition.

By default, it is assumed that each transition will be modeled separately as the basis for prediction. LCM creates names for each of these sub-models. These names can be changed to any name of convenience. If you wish to model several transitions together, merely give them a common sub-model name. Note, however, that:

- Modeling multiple transitions together is only available using the Multi-Layer Perceptron (MLP) option. Logistic Regression requires that they be modeled separately.

- Transitions should be grouped only if you believe that the underlying driving forces of change are the same.

- In general, as the number of transitions that are grouped together increases, the task becomes a more and more difficult one for MLP to solve. This can easily be gauged from the validation accuracy report that the MLP provides.

Finally note that the Sub-Model to be Evaluated drop-down combo-box is the manner in which you indicate which transition will be modeled in any specific run of logistic regression or the MLP.

The Variable Transformation Utility Panel

The Variable Transformation Utility Panel provides a selection of optional commonly used transformations. These are particularly critical if the Logistic Regression modeling option is chosen since it requires that the variables be linearly related to the potential for transition. The MLP option does not require the variables to be linearly related, but transformation can sometimes make the task easier for it to solve in cases of strong non-linearities, thus yielding a higher accuracy. In general, the transformations are self-evident, but two require special mention.

- The natural log transformation is commonly effective in linearizing distance decay variables (e.g., proximity to roads).

- The evidence likelihood transformation is a *very effective* means of incorporating categorical variables into the analysis. For both the logistic regression and MLP options, variables must either be converted into a set of Boolean (dummy) variables, or transformed using the evidence likelihood transformation option (highly recommended). For more information on this option, see Note 1 in the section titled **How It Works** in this chapter.

The Test and Selection of Site and Driver Variables Panel

This is an optional panel that provides a quick test of the potential explanatory power of a variable – simply specify the variable of interest and click the Test Explanatory Power button. Both quantitative and qualitative variables can be tested (note, however, that qualitative variables need either to be broken out to a set of separate Boolean layers or transformed with the Evidence Likelihood transformation tool before use). In general, we have found the variables that have a Cramer's V of about 0.15 or higher are useful while those with values of 0.4 or higher are good. For details, see Note 2 in the section titled **How It Works** in this chapter.

For convenience, an Add to Model button is provided. This simply inserts the tested variable into the sub-model structure grid.

The Transition Sub-Model Structure Panel

The Transition Sub-Model Structure panel provides a table for specifying:

- The explanatory variables to be evaluated. They can be added by means of the Test and Selection of Site and Driver Variables panel, or directly entered.

- Whether each variable is static or dynamic. Static variables are site variables that do not change over time, such as slope, element, etc. Dynamic variables are those that do change over time, such as proximity to development or proximity to roads (assuming dynamic road growth).

- If the variable is dynamic, whether the basis is a landcover category (such as proximity to urban) or a roads category (such as proximity to secondary roads).

- If the variable is dynamic, whether the operation is a DISTANCE calculation or a MACRO. The former is the most common and will calculate distance from the designated landcover or road categories. The MACRO option leaves open an infinite set of possibilities. If MACRO is selected, LCM will search for an IDRISI macro file (a text file with an ".iml" extension) that contains the complete sequence of operations to update the dynamic variable at that stage. The macro file must have the same name as the original dynamic variable, but with an ".iml" extension. LCM will pass four parameters to the macro (%1, %2, %3 and %4) as follows:

The filename of the current state of the dynamic variable.

The filename of the updated dynamic variable that must be created.

The name of the final output landcover image from the complete run.

The name of the final output roads image from the complete run.

In most cases, only parameters %1 and %2 will be needed. Note that for the MACRO option, the basis type must be specified as Other.

When a variable is designated as dynamic and the basis layer type is selected as either roads or landuse, a dialog will pop up for specifying the relevant landcover category or road categories from which distance should be calculated in the change prediction stage. If a roads layer was not specified in the LCM Project Parameters tab, you will be able to specify this layer in the dialog and it will update the basis roads layer field in the LCM Project Parameters tab.

Note that:

- Only one landcover category can be specified as the basis for calculating a dynamic landcover distance relationship. The land cover list is taken from the input land cover image.

- Dynamic road development recognizes three categories: primary, secondary and tertiary. These must be given identifiers of 1, 2 and 3 in your roads layer. You may then select any combination of categories for road building (e.g., all three, just tertiary, etc.)

The Run Transition Sub-Model Panel

The Run Transition Sub-Model panel is the where the actual modeling of transition sub-models is implemented. The specific sub-model that will be implemented is that specified in the Sub-Model to be Evaluated drop-down combo box in the Transition Sub-Models: Status panel.

Two methodologies are provided for modeling: a Multi-Layer Perceptron (MLP) and Logistic Regression. In general, we strongly recommend the former which is why it is the default choice. In either case, when the Run Sub-Model button is clicked, samples are extracted from the two landcover maps provided of areas that underwent the transitions being modeled as well as the areas that were eligible to change, but did not. Then, in both cases, a modeling dialog will be launched automatically, as described below:

Multi-Layer Perceptron

Initially the dialog for the Multi-Layer Perceptron neural network may seem daunting, but most of the parameters presented do not need to be modified (or in fact understood) to make productive use of this very powerful technique.

As launched by LCM, the Multi-Layer Perceptron starts training on the samples it has been provided of pixels that have and have not experienced the transitions being modeled. At this point, the MLP is operating in *automatic* mode whereby it makes its own decisions about the parameters to be used and how they should be changed to better model the data. In most cases, you can let it run in this mode until it completes its training. However, you are also free to stop its training operation, modify parameters and start it training again. Ultimately, after training has been completed, you will need to click the Classify button to complete the process of transition potential modeling. When it is finished, LCM will display each of the transition potential models. For more information about LCM's specific use of the MLP, see Note 3 in the section titled **How It Works** in this chapter. For detailed information on the MLP parameters, see the on-line Help System for MLP.

Note some specific tips on using MLP in this context:

- The critical factor in the use of the MLP is the learning rate. What you ideally want to achieve is a smooth descent of the RMS error curve. If it is flat over a large number of iterations (more than 2000), stop the training (by clicking the Stop button) and halve the start and end learning rates. Continue to do this as necessary until the error curve descends.

- If the RMS error curve has descended and flattens out over a large number of iterations (>1000), stop the training and proceed to the *Classify* button. If, however, you experience a slow but progressive increase in accuracy and decrease in the RMS errors, let the MLP run until the end of its iterations. If it reaches the end of its iterations and it still appears to be learning (the accuracy is increasing and the RMS is dropping), re-run it with a larger number of iterations (e.g., an additional 25%).

- In general, manipulating the learning rate alone will yield better than 90-95% of the best solution. In general, we do not recommend modifying the momentum factor and have not found that adding a second hidden layer has been helpful. Two parameters have sometimes been helpful in achieving the best solution. The first is the Sigmoid Constant: a value greater than 1 (generally not more than 10) will make the decision boundary between good and bad locations less steep. The second is the number of hidden layer nodes. With a small number relative to the number of input layers, the hidden layers act like canonical components, expressing the common underlying themes in the explanatory variables. With large numbers relative to the number of explanatory variables, the nodes capture very specific characteristics. In general, we have found that the default algorithm performs well, but do not hesitate to experiment. The accuracy rate of classifying the validation pixels is a good gauge.

- The linear activation level options of MLP are not recommended for this application.

Logistic Regression

In contrast to the MLP, logistic regression can only model a single transition at a time. Thus it launches in a mode that is ready to model the specific transition indicated in the drop-down combo box in the Transition Sub-Models: Status panel.

The Change Prediction Tab

The Change Prediction tab provides the controls for a dynamic landcover change prediction process. After specifying the end date, the quantity of change in each transition can either be modeled through a Markov Chain analysis or by specifying the transition probability matrix from an external (e.g., econometric) model. Two basic models of change are provided: a hard prediction model and a soft prediction model. The hard prediction model is based on a competitive land allocation model similar to a multi-objective decision process. The soft prediction yields a map of vulnerability to change for the selected set of transitions. In general, we prefer the results of the soft prediction for habitat and biodiversity assessment. The hard prediction yields only a single realization while the soft prediction is a comprehensive assessment of change potential.

In setting up the change prediction analysis, the user can specify the number of dynamic reassessment stages during which dynamic variables are updated. This also includes the optional dynamic growth (intensification) of the road network. At each stage, the system also checks for the presence of planning interventions (see below), including incentives and constraints and major infrastructure improvements.

Critical Things to Know!

1. The Change Prediction tab uses information from several other tabs. Of critical importance, all included transitions in the Transition Potentials tab must have been already modeled using either MLP or logistic regression.

2. The options to include infrastructural changes or incentives and constraints require that the appropriate panels be filled on the Planning tab.

The Change Demand Modeling Panel

The default procedure for determining the amount of change that will occur to some point in the future is by means of a Markov Chain. A Markovian process is one in which the state of a system can be determined by knowing its previous state and the probability of transitioning from each state to each other state. To determine this, LCM makes a call to IDRISI's MARKOV module at the time a prediction is run. Using the earlier and later landcover maps along with the date specified, MARKOV figures out exactly how much land would be expected to transition from the later date to the prediction date based on a projection of the transition potentials into the future. Note that this is not a simple linear extrapolation since the transition potentials change over time as the various transitions in effect reach an equilibrium state.

To use the default Markov transition probabilities, first enter the end prediction date. Then select to view the resulting Markov matrix. This matrix can be edited and saved but all rows must sum to one. If you do edit the default matrix, you can always elect to restore the original matrix. The default Markov matrix that is saved to a file is a concatenation of the project name, the year and the keyword "transition_ probabilities," and has a ".txt" extension. For example, if the project is named CT and the year of prediction is 2006, the file will be named "CT_2006_transition_probabilities.txt."

The alternative to determining the demand for change by Markovian projection is to specify a transition probability file from some other projection tool, such as an econometric model. The format for this file is as follows:

- It must be an ASCII text file with a ".txt" extension.

- It must be a square matrix where the numbers of rows and columns are each the same as the number of landcover classes associated with your landcover maps.

- The rows represent the landcover classes on the earlier landcover map where the first class occupies the first row. The columns represent the classes on the later map.

- All rows must sum to 1.0.

Finally note that regardless of how the transition probability matrix was created, the option exists to edit its values by clicking on the designated button.

If you choose to enter transition probabilities by means of an external model, note that LCM will indicate that you need to import the file. Click on the Import button and it will then display the contents of the file in a separate grid so that you can be sure that it is correct. If so, click on the OK to Import button. It will then indicate that the default matrix has been altered. At any time you can choose to reconstruct the original matrix or re-enter your external model as necessary.

The Dynamic Road Development Panel

This panel sets the parameters for dynamic road development. Dynamic road development is a procedure that tries to predict how roads will develop in the future. It is very experimental and we welcome your suggestions for improvements or extensions of its capabilities[1].

Three levels of roads are recognized: primary, secondary and tertiary, which must be coded with integer values 1, 2 and 3, respectively. Primary roads can only grow by extending their endpoints (if endpoints exist within the map). Secondary roads can grow as new branches off of primary roads, and they can extend themselves. In a similar manner, tertiary roads can grow as new branches off of secondary roads, and they can extend themselves.

Growth Pattern Options

Five options are provided according to the manner in which new road end-points and new road routes are generated:

Road Growth Parameters

The critical control parameters for dynamic road development are ***road spacing*** and ***road length***. The former dictates the frequency with which roads are generated along a route of superior class. Specifically it is the minimum distance that must separate roads along a route of superior class. The latter dictates the maximum length a road class will grow in each dynamic stage. The actual length of any new segment will fall randomly within that range.

Mode of End-Point Generation

Within the limits of the controlling parameters, new road end-points can be generated either randomly or by means of a procedure that looks for the location of highest transition potential, but with a stochastic perturbation. Rather than picking the location with the absolute highest transition potential within the growth length parameter, a small random perturbation is added to the transition potentials such that there is a large chance it will pick a location very similar to the highest

1. Dynamic road development in IDRISI was inspired by the pioneering work of the DINAMICA team. See Soares-Filho, B.S.; Assunção, R.M.; Pantuzzo, A. Modeling the spatial transition probabilities of landscape dynamics in an Amazonian colonization frontier. *BioScience,* v. 51, p.1039-1046, 2001.

transition potential and an increasingly less likely chance of taking one that is quite different.

Note that if the stochastic highest transition potential option is used, a grid showing the selected transitions will be enabled. You should select the transitions which are relevant for road growth and exclude those that are not. For example, your model might include transitions related to declines in agriculture as well as urbanization. Clearly declines in agriculture would not be a basis for road growth.

Mode of Route Generation

Once a new endpoint for a road has been generated, two options are provided for how the route is selected in joining up that location to the existing road network. The default option is the minimum gradient route. This route is a balance between trying to achieve a short route and the need to avoid steep slopes as much as possible. Alternatively, the highest transition potential route balances the need for a short route with the desire to link up as many areas of high transition potential as possible (on the assumption that these are areas that will have a high likelihood of needing a road connection in the future).

Note that if the highest transition potential route option is used, a grid showing the selected transitions will be enabled. You should select the transitions which are relevant for road growth and exclude those that are not. These are the same transitions that would be relevant for end point generation (see above).

Skip Factor

In our experience, we have found that it is sometimes more efficient to not build roads at every stage, but build them only after several stages have passed. The skip factor is how this is set. A skip factor of 1 means that roads will be dynamically built at every stage. A skip factor of 2 indicates that they should be built only every second stage, and so on.

Output Roads Layer

The name of the output roads layer will be used for the final output at the end of the prediction. For intermediate stages, this name will be used as a prefix with a suffix that indicates the stage number. These intermediate images are saved and are also used for the construction of movie loops. If you do not wish to keep the intermediates, you will need to delete them by hand. Note that this name should be different from that used for the landcover prediction.

The Change Allocation Panel

The Change Allocation Panel parameterizes and initiates the actual prediction process. The following parameters need to be set:

The Prediction Date

This is set using the Change Demand Modeling panel (see above).

Dynamic Variable Recalculation Stages

Given the prediction date and the date of the later landcover image, the number of recalculation stages dictates the frequency with which dynamic elements are recalculated. At each recalculation stage:

- Dynamic landcover variables are recalculated. A dynamic variable is one which varies in character with time. For example, one of the variables associated with a specific transition might be distance from deforested areas. As time progresses, the extent of this deforested area will increase, thereby changing this distance variable. All explanatory variables that are indicated as being dynamic are recalculated at each stage.

- Dynamic road building is undertaken (unless a skip factor has been specified). Dynamic road building is a predictive modeling of the development of roads over time.

- Infrastructural changes are reviewed and incorporated as necessary. These are specified on the Planning tab.

- Incentives and constraints are applied to the solution. These are also specified on the Planning tab

Hard Versus Soft Prediction

LCM offers two modes of change prediction: hard and soft. A hard prediction is a commitment to a specific scenario. The result is a landcover map with the same categories as the inputs. In contrast, the soft output is a continuous mapping of vulnerability to change. It doesn't say what *will* change, but rather, the degree to which the areas have the right conditions to precipitate change.

If the soft prediction checkbox is checked, the system will produce *both* hard and soft outputs. In addition, when checked, a grid will open up listing all included transitions in your model. Here you can select which transitions you wish to include in your portrait of vulnerability. As a default, all are selected, in which case you are modeling the vulnerability to any kind of change. More typically, you will select only certain transitions to include. For example, if your interest is in forests, you might include all transitions that relate to the loss of forest cover.

A second issue that needs to be set for the soft prediction is the aggregation type. The soft prediction is based on the current state (during the prediction) of transition potentials for each of the selected transitions. These are then aggregated to produce the soft output for each stage. Two aggregation options are provided: ***maximum*** and ***logical OR***. The former characterizes a pixel by the maximum transition probability that exists at that location for the included transitions. The second calculates the logical OR of these transition potentials. This latter option treats a location as being more vulnerable if it is wanted by several transitions at the same time. For example, if a certain pixel is evaluated as 0.6 as it's potential to transition to one cover type and 0.7 to another cover type, the former option would calculate its vulnerability to change as 0.7 while the latter would evaluate it at 0.88. It is left to the user to decide which is the more appropriate in the context of the study being undertaken.

Display Options

LCM provides several options for display of the prediction. One is to display the intermediate stage images (as opposed to only the final prediction). This option should be used with care as Windows display memory can be rapidly exhausted, putting the entire Windows system into an unstable state. The limits here will depend, in part, on how much RAM is installed on your system.

A second option for display is to create an AVI video file. In IDRISI, this file can be played in IDRISI's Media Viewer – a utility provided under the Display menu. It can also be played with programs such as Microsoft Media Player and can be inserted into a Microsoft PowerPoint presentation. For long sequences, a frame rate of 0.25 generally works well, but slower rates may be more appropriate for slower sequences.

For more information about how the hard allocation procedure is undertaken, see the section titled **How It Works** in this chapter.

The Validation Panel

The Validation panel allows you to determine the quality of the predicted land use map in relation to a map of reality. It does this by running a 3-way crosstabulation between the later landcover map, the prediction map, and a map of reality. The output will illustrate the accuracy of the model results where:

A | B | B = Hits (green) – Model predicted change and it changed

A | A | B = Misses (red) – Model predicted persistence and it changed

A | B | A = False Alarms (yellow) – Model predicted change and it persisted

The Implications Tab

In assessing the impact of change for ecological sustainability, a wide range of tools is provided, including those for species-specific habitat assessment, habitat change analysis, gap analysis, landscape pattern analysis and biodiversity analysis.

Critical Things to Know!

1. The Habitat Assessment panel ideally uses a habitat suitability map that has a 0-1 range, and which can be created with the Habitat Suitability / Species Distribution panel. It is strongly recommended that you read the section about it below.

2. The categories of habitat and potential corridor are completely open in terms of their definition.

3. Depending upon the input data, the Biodiversity Analysis panel may generate a *very* large number of intermediate data files that you may wish to be automatically deleted upon completion of the analysis.

The Habitat Assessment Panel

The Habitat Assessment panel allows one to assess the status of habitat on an animal species-specific basis[2]. Based on any of the existing or predicted landcover maps and an optional map of species-specific habitat suitability (see below), the habitat assessment tool develops a map with five categories: primary habitat, secondary habitat, primary potential corridor, secondary potential corridor and unsuitable. Important parameters that control this process include home range sizes, buffers based on sensitivity to humans and the ability to cross gaps within home ranges and during dispersal. The resulting map can be used to estimate maximum populations and serves as a primary resource in the planning for corridors.

Any of three analyses can be run: an assessment of the earlier landcover map, the later landcover map or the current prediction. Important terms and parameters that need to be specified include:

Habitat and Potential Corridor

The habitat assessment map produced by this analysis includes five categories of habitat status. Below they are indicated with a possible interpretation. However, they can be interpreted in any way that seems appropriate to the study under consideration.

Primary Habitat. This is habitat that meets all the necessary life needs in terms of home range size, access to summer and winter forage, etc. Issues other than minimum area and required buffer size are specified by a minimum suitability on a habitat suitability map (see below).

Secondary Habitat. This includes areas which have the designated habitat cover types, but which are missing one or more requirements (such as area or minimum suitability level) to serve as primary habitat. Secondary habitat areas provide areas of forage and safe haven for dispersing animals as they move to new areas of primary habitat.

Primary Potential Corridor. Areas of primary potential corridor are non-habitat areas that are reasonably safe to traverse, such as at night.

Secondary Potential Corridor. There are areas that are known to be traversed by the species in question, but which constitute much riskier cover types.

Unsuitable. These are areas that are not suited for habitat or corridors.

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2. The habitat assessment procedure introduced here was inspired by the work of the Bow Corridor Ecosystem Advisory Group (BCEAG) in the development of a corridor strategy for the Southern Canmore Region of Alberta, Canada. For more information, please refer to http://www.stratalink.com/corridors/wildlife_corridors_report.htm.

Include as Potential Habitat

The grid lists each of the landcover types included in the study. Select all cover types associated with habitat for the species in question.

Gap Distance Within Range

This column is concerned with gaps within the home range of the species of concern. Gap distances do not need to be specified by cover types included as potential habitat components.

Gap Distance Outside Range

This column is concerned with gaps that the animal is capable of crossing when dispersing. This parameter is important in determining which areas can serve as potential corridors. In addition, this parameter effectively establishes the maximum length of the corridor.

Minimum Core Area

This constitutes, in the case of primary habitat, the minimum home range area of the species involved, exclusive of any buffers (hence the use of the term *core*). For secondary habitat areas, the core area is more likely related to forage abundance.

Minimum Edge Buffer

This is the size of buffer needed as distance from human activity. For potential corridor areas, this therefore constitutes half the necessary corridor width.

Minimum Habitat Suitability

The inclusion of a habitat suitability model is optional but strongly recommended. For each of the main habitat/corridor categories, a minimum suitability can be specified for inclusion in that category. A general strategy for development of this layer is as follows:

1. Develop separate suitability maps for each of the primary and secondary habitat and potential corridor categories. The Habitat Suitability / Species Distribution panel provides a variety of tools for empirically developing this. However, the multi-criteria evaluation (MCE) option will most often be the tool of choice since the suitability mapping will be based on published reports of species/landscape associations.

2. Rescale the range of the primary habitat suitability map to a range of 0.75-1.0 using the STRETCH module. Then rescale the secondary habitat map to a 0.5-0.75 range; the primary potential corridor map to a 0.25 – 0.5 range and the secondary potential corridor map to a 0 – 0.25 range. Combine these four maps using the *cover* option in OVERLAY. The result will be a single map layer that ranges in value from 0.0-1.0. The default thresholds in LCM are set for 0.75, 0.5 and 0.25 in the decision for allocating land to the basic categories (before consideration of minimum area, gap crossing and buffer considerations). All areas with a value of 0 are by definition *unsuitable*.

In practice, the user is free to establish whatever thresholds are meaningful and logical in the context of their study.

The Habitat Change / Gap Analysis Panel

This panel is used for two kinds of analyses: an analysis of change in habitat status (created by means of two runs of the Habitat Assessment panel) and Gap Analysis by comparing the results of one run of the Habitat Assessment panel and a protection layer map.

In the case of habitat change, a graph is produced of gains and losses that can be altered with one of net change.

With gap analysis, the protection map can be either a simple Boolean image showing areas that are protected or not, or a multi-level integer map showing various protection levels. The result is simply a crosstabulation of habitat categories and protection levels.

The Landscape Pattern and Change Process Analysis Panel

This panel permits analyses of landscape pattern or process of any of the earlier or later landcover maps, or the current prediction. Options include:

Normalized Entropy

This measure is Shannon's Entropy measure normalized by the maximum entropy for the number of landcover classes involved. Another common term for this measure is Diversity. It is calculated over the local neighborhood of each pixel, defined as either a 3x3, 5x5 or 7x7 neighborhood. The formula is as follows:

$E = -\Sigma(p*\ln(p)) / \ln(n)$

where *p* is the proportion of each class within the neighborhood, *ln* is the natural logarithm[3] and *n* is the number of classes. The result is an index that ranges from 0-1 where 0 indicates a case where the landcover is uniform within the neighborhood and 1 indicates maximum diversity possible of landcovers within the neighborhood.

Relative Richness

This is another measure of diversity of cover classes, measured as:

$R = n/nmax*100$

where *n* is the number of different classes present in the neighborhood and *nmax* is maximum number of classes possible.

Edge Density

Edge Density is a simple measure of fragmentation. Edge density is tabulated as the number of adjacent pairs of pixels within the neighborhood that are different from each other relative to the maximum number of different pairs possible.

Patch Area

Patch Area groups adjacent pixels of similar landcover category into patches, calculates their areas, and outputs an image where each pixel expresses the area of the patch to which it belongs.

Patch Compactness

Patch Compactness groups adjacent pixels of similar landcover category into patches, calculates their compactness, and outputs an image where each pixel expresses the compactness of the patch to which it belongs. Compactness is calculated as:

C = SQRT(Ap/Ac)

where SQRT is the square root function, Ap is the area of the patch being calculated, and Ac is the area of a circle having the same perimeter as that of the patch being calculated.

Change Process

The Change Process option compares the earlier and later landcover maps and measures the nature of the change underway within each landcover class. It does this by using a decision tree procedure that compares the number of landcover patches present within each class between the two time periods to changes in their areas and perimeters.[4] The output is in

3. Log base 2 is more commonly used in communications theory, but the difference is immaterial with this normalized procedure.

the form of a map where each landcover class is assigned the category of change that it is experiencing. The interpretation of the categories is as follows:

Deformation: the shape is changing.

Shift: the position is changing.

Perforation: the number of patches is constant but the area is decreasing.

Shrinkage: the area and perimeter are decreasing but the number of patches is constant.

Enlargement: the number of patches is constant but the area is increasing.

Attrition: the number of patches and the area are decreasing.

Aggregation: the number of patches is decreasing but area is constant or increasing.

Creation: the number of patches and area are increasing.

Dissection: the number of patches is increasing and the area is decreasing.

Fragmentation: the number of patches is increasing and area is strongly decreasing.

Note, however, that while the output is in the form of a map, it is not spatially explicit – i.e., the process attributed to a landcover category is uniform over the entire study area.

The Species Range Polygon Refinement Panel

This panel allows for the refinement of range polygon maps of species distributions developed by experts who draw the ranges onto map bases. This information is exceptionally valuable, but subject to error as a result of imprecision in the base maps, projection and geodetic datum errors, and limited geographical extent of expertise (i.e., the expert delineates only in the areas where she or he has expertise). This procedure is very experimental, but had shown considerable promise. Comments are invited on its utility and how it can be improved.

General Logic

The underlying principle of the refinement process is to uncover the common environmental logic of the areas delineated by the range polygon. It does this by creating clusters of environmental conditions according to a set of environmental variables that the user believes can characterize the niche of the species. It then compares these clusters with the range polygon to determine the proportional inclusion of clusters within the range polygon. Clusters that fall wholly or largely within the polygon are assumed to describe essential components of that niche. Those that fall mostly or wholly outside are assumed to be unlikely components. The polygon is thus refined by removing areas that fall below a designated confidence. In addition, another option is provided to simply output a confidence map that can be used in conjunction with the original range polygon by the Weighted Mahalanobis Typicality procedure in the Habitat Suitability / Species Distribution panel. This is the default option and the one we generally recommend.

Environmental Variables and Cluster Development

The critical component of this analysis is the production of environmental clusters. For this you will need to supply a set of environmental variables that can describe basic environmental conditions. Because of the clustering technique used, this is limited to a maximum of seven variables[5]. To stay within this limit, we strongly recommend the use of Principal Components Analysis as a way of reducing a larger set of variables to a smaller set of highly informative components. That said, you should avoid the inclusion of components with very low explanatory power.

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4. This is an implementation of the procedure outlined in Bogaert, J., Ceulemans, R., and Salvador-Van Eysenrode, D. (2004) "Decision tree algorithm for detection of spatial processes in landscape transformation." Environmental Management, 33, 1, 62-73.

What variables should be used? This should be decided in the context of the species being modeled. However, generally you would include variables that relate to the seasonal and interannual availability of energy and water. Commonly used factors include elevation and slope (because of their relationship to temperature and soil moisture), the first and second principal components of mean monthly Normalized Difference Vegetation Index (NDVI) imagery (as a statement of realized long term and seasonal growing conditions), the long term coefficient of variability in NDVI (as a statement of interannual variability), and the first two components of mean monthly precipitation and temperature.

Output Options

Four output options are provided:

1. Presence. This is a refined range polygon where areas that are poorly associated with the core environmental characteristics of the original range polygon are removed.

2. Presence/Pseudo-Absence. The output is the same as the above except that areas that are extremely unlikely to be associated with the core environmental characteristics of the original range polygon are treated as absence while only those that have a close association are considered as presence.

3. Confidence. This is the default option and the one we generally recommend. Each pixel within the original polygon is assigned a confidence value from 0-1 based on how well it fits the general nature of a coherent pattern of environmental conditions (as will be explained further below).

4. Thresholded Confidence. This option is the same as the above, except that areas that fall below a minimum specified confidence are forced to have a confidence of zero.

Thresholds

For all options except the Confidence output, an upper and/or lower threshold will need to be selected to establish areas of presence or absence. The default thresholds will serve as a general guideline of the values that would be used. In general, for presence, you are looking for a value that separates a clear group of clusters that strongly overlap the range polygon, while for absence you want to isolate clusters that have very little or no presence in the polygon. In many instances, this is very hard to do, which is why we recommend the use of the Confidence option coupled with the Weighted Mahalanobis Typicality procedure in the Habitat Suitability / Species Distribution panel. Using this option, no decision needs to be made.

Background Mask

The background mask option is quite important to the use of this procedure. If you are modeling a land species and are working in an area with significant ocean areas, you should provide a mask image to remove these from the calculations of proportional areas. The mask should have 1's over land areas and 0's over water areas. For marine species, clearly the opposite applies.

A Note About the Presence / Absence Option

The presence/absence option is provided to allow the use of modeling procedures that require absence data (such as logistic regression). However, bear in mind that the absences are really pseudo-absences. To account for sampling issues, the absence pixels are chosen as a random sample of those that meet the lower threshold criterion such that the number matches (given some variance associated with the random selection process) the number of presence pixels.

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5. We tested several clustering procedures including K-Means, Fuzzy ARTMAP and SOM. However, the Histogram Peak technique provided by the CLUSTER module in IDRISI was so much superior to the others that we decided to use it despite the limitation on the number of independent variables that could be used.

The Habitat Suitability / Species Distribution Panel

This panel provides a set of tools for developing habitat suitability and species distribution maps. The specific options available depend upon the nature of the training data, if any, that will be used: presence only, presence/absence, abundance or none (see below). In all cases, you will need to specify a set of environmental variables that define the species habitat or niche.

Environmental Variables: Habitat Suitability Mapping

For habitat suitability mapping, the variables used likely relate to habitat landcover types, proximity to summer and winter foraging areas, proximity to human disturbance and so on. All variables specified must be continuous variables unless the multi-criteria evaluation (MCE) option is used. For all but the MCE option, categorical variables should be converted to a series of Boolean layers (also known as *dummy* variables). For the instance where MCE is used, an assignment procedure is provided that will allow you to assign suitabilities to categorical variable classes. Also with the MCE option, you will be able to add Boolean constraints separately in the special dialog that will be launched.

Environmental Variables: Species Distribution Modeling

The variables that should be used for species distribution modeling should be decided in the context of the species being modeled. Generally you would include variables that relate to the seasonal and interannual availability of energy and water. Commonly used factors include elevation and slope (because of their relationship to temperature and soil moisture), the first and second principal components of mean monthly Normalized Difference Vegetation Index (NDVI) imagery (as a statement of realized long term and seasonal growing conditions), the long term coefficient of variability in NDVI (as a statement of interannual variability), and the first two components of mean monthly precipitation and temperature.

No Training Data – MCE

The Multi-Criteria Evaluation option is designed for cases where training data are not available but where studies are available to guide the development of a suitability or distribution map by means of a multi-criteria evaluation. After the environmental variables and output filename have been entered, clicking on the Run button will launch a special dialog that combines the features of the FUZZY and MCE modules of IDRISI.

The first and *very* important stage in the analysis is to convert each of the environmental variables to factors. The difference between the two is that a variable is unscaled with respect to the model while a factor is scaled to a specific numeric range using a scaling procedure that is directly related to the expression of suitability. For example, if one were modeling a species that is sensitive to humans, a distance from human settlement layer might be used. Suitability would clearly be worst within and immediately next to areas of human occupation. As you move farther away, the land is becoming increasingly better up to a limit. It might be that once one reaches a distance of 2 kilometers, being further is now irrelevant – it is far enough away. In this case maximum suitability (on the basis of this variable alone) will have been reached. Thus we should rescale the variable such that suitability is 0 at the edge of human occupation and increases in value until it reaches its maximum at 2 km, and remains at that value for all greater distances. In the transition of multi-criteria evaluation, this process is known as *standardization*, but in reality one is recasting the data into an expression of membership in the fuzzy set of suitable lands.

Two options are provided for standardization: a call to the FUZZY module in IDRISI or a call to the ASSIGN module. The former is designed for the standardization of continuous variables such as in the example above while the latter is intended for the standardization of categorical variables. Note that in contrast to the standardization used in IDRISI's multi-objective decision making procedure, standardization here uses a 0.0-1.0 scaling range.

MCE General Procedure

Your general procedure will be as follows:

Highlight each variable in turn in the upper-left grid. Note that it shows you the minimum and maximum values.

Select the standardization option and indicate the factor output filename. Then click the "Add to Model" button and the factor will be created and added as a factor in the factor grid.

Assign a weight to each factor. Factor weights can be any numeric value that is convenient for expressing the relative importance of each to the final suitability map. The weights will automatically be normalized to a 0.0-1.0 range before use.

Add any constraints necessary. Contraints are Boolean images which exclude areas from consideration. They should have 0's in constrained areas and 1's otherwise.

Choose an aggregation option (see below) and then click OK to create the suitability map.

Note that factors can also be added or removed directly from the factors grid. However, be sure that any directly added factors have a 0.0-1.0 numeric range.

Standardization Options

The FUZZY Option

With the FUZZY option, you need to indicate the nature of the relationship between the variable and suitability. The graph will illustrate each case along with the general positions of the control points for linking the curve to your variable. The graph will also indicate the nature of the various shape options. For further information, please refer to the on-line Help System on the FUZZY module.

The ASSIGN Option

With the ASSIGN option, you will be provided with a grid in which you must indicate the identifiers of classes in the left-hand column and the suitabilities that should be assigned in the right-hand column (on a 0.0-1.0 range). Any classes that are not included in this grid will automatically be assigned a value of 0.

Aggregation Options

The aggregation options dictate how the factors will be combined to create a single suitability map. The default is weighted linear combination (WLC) which is appropriate when you wish the factors to trade-off (i.e., to allow poor qualities to be compensated by good qualities). The Minimum operator allows no trade-off and characterizes each location by its worst quality. This is clearly the most conservative operator. The Maximum operator also allows no trade-off, but characterizes locations by their best quality.

If you find that you have some factors that should trade-off and others that should not, process the group that do trade-off first. Then combine that result with the others that do not trade-off using either the Minimum or Maximum operator.

Presence Data

Presence data is probably the most common form of training data for species modeling – it records where the species has been observed, but not where it has been observed to be absent. Two procedures are available for dealing with these data.

Mahalanobis Typicality

The Mahalanobis Typicality option assumes that the underlying species distribution is normal with respect to environmental gradients. However, our tests have shown that it performs reasonably even with mildly skewed data. The output is in the form of typicality probabilities – an expression of how typical the pixel is of examples it was trained on. Thus a value of 1.0 would indicate a location that is identical to the mean of environmental conditions that were evident in the training data. However, be careful about the interpretation of low typicalities. Since typicalities express the full range of variability, a low typicality may be unusual, but still legitimately a location that is part of the species' range. If you are looking for a threshold for when to consider an area as being unlikely to be part of its range, it is likely to be a very low value (e.g., 0.001). As an illustration of this concept, consider the case of a blue lobster. Blue lobsters are very rare, but they are still lobsters! See the on-line Help System for MAHALCLASS for further information.

Weighted Mahalanobis Typicality (Recommended)

This option requires both a training site file and a confidence (weight) file. It was intended that this option would be used with the confidence output of the Species Range Polygon Refinement panel. A confidence/weight image contains values from 0.0-1.0 that express the degree of confidence that the pixel is truly a member of the species' range. IDRISI uses this file along with a corresponding training file and submits them to the FUZSIG module for developing the signature statistics that are needed by MAHALCLASS. FUZSIG creates a weighted multivariate mean and variance/covariance matrix based on the confidence weights. Our experience with this procedure has been excellent and we strongly recommend it.

Presence / Absence Data

With presence/absence data, a range of techniques opens up. These include:

Mahalanobis Typicality

Please see the entry under Presence Data above for information about this option.

Weighted Mahalanobis Typicality

Please see the entry under Presence Data above for information about this option.

Multi-Layer Perceptron

This option will launch the MLP module with the selected environmental variables loaded. Please refer to the on-line Help System for MLP regarding this option.

Logistic Regression

This option will launch the LOGISTICREG module with the selected environmental variables loaded. Please refer to the on-line Help System for LOGISTICREG regarding this option.

Abundance Option

With abundance data, the MULTIREG (multiple regression) option is launched with the selected environmental variables loaded. Please refer to the on-line Help System for MULTIREG regarding this option.

A Note About Input Data

The input to this procedure can be vector, raster, XY-Text or XY-CSV. XY-Text is a text file format suitable for presence point data, where each location is referenced by an X and Y coordinate separated by one or more spaces or tabs. XY-CSV (comma separated values) is similar except that the X and Y pair are separated by a comma. For all other tabular formats, we recommend that you load the data into Database Workshop and output the data as a vector file. Database Workshop can accept a wide range of formats (including DBF, MDB, XLS and CSV) and allows you to sort and subset before outputting to a vector or raster layer.

The Biodiversity Analysis Panel

The Biodiversity Analysis panel provides the ability to produce a spatially explicit mapping of:

> Alpha Diversity: the total number of considered species at each location.
>
> Gamma Diversity: the total number of considered species over a large region.
>
> Beta Diversity: the ratio of Gamma to average Alpha Diversity over a large region, and thus a measure of the turnover of species. There are many measures of beta diversity that have been proposed. The measure used here

is the original Whittaker's beta diversity.

Sorensen Dissimilarity: a measure of species compositional dissimilarity.

Range Restriction: a continuous measure of vulnerability that can also be interpreted as a measure of endemism.

Input Data

In all cases, the input for this analysis is in the form of species range polygons. Three input formats are supported. The first is a vector composite polygon where all species polygons are contained within the same vector file. The second is a vector group file that lists the names of a set of vector files that contain the range polygons for a single species[6]. The third is a raster group file that lists a set of raster files that contain the rasterized range polygons of a single species.

With the exception of Alpha Diversity, the data must ultimately be converted to a raster form for analysis. Thus if a vector group file is supplied, each file is rasterized (using the spatial characteristics of the reference file) and a raster group file is created with the same name as the vector group file. If a vector composite file is used, it is first broken out into a set of separate vector files along with a vector group file of the same name as the vector composite file. These vector files are then in turn rasterized.

An Important Note

Because of the potentially large number of files that may be generated by this analysis, the option is provided to delete generated intermediate layers. However, if you intend on running further analyses with the same data, it is recommended that you do not choose this option until the last run and that subsequent analyses be run from the raster group file.

Regional Definition

All measures except Alpha Diversity and the Range Restriction Index require the definition of a region over which the index is calculated. Three options are provided. The vector and raster region polygon options will yield a mapping where all pixels within a region (such as an ecoregion) will have the same index value. The focal zone option, however, is quite different and can produce a different value at each pixel location.

The focal zone option calculates values by comparing the species composition in each pixel to those in a circular zone surrounding it. To use the focal zone option, you must set the focal zone diameter (e.g., 50 km). This focal zone is moved successively over every pixel in the image. As a consequence, the analysis does take considerable time to complete. Continental scale analyses at a moderate resolution (e.g., 1 km) are probably best set up at the end of the day so that they can run overnight.

Alpha Diversity

Alpha Diversity is computed simply as the richness of species at each location – i.e., it is the total number of species found at each location.

Gamma Diversity

Gamma Diversity is calculated as the richness of species over a region. Thus the value recorded at any pixel represents the richness within the region to which it belongs and not the richness at that particular spot.

Beta Diversity

Beta Diversity is calculated as gamma diversity divided by the average alpha diversity within each region. This formulation is the original one developed by Whittaker (1972)[7].

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6. Vector group files have the same format as raster group files. At this time, vector group files are only used for the biodiversity analyses in LCM.

Sorensen Dissimilarity

Sorensen's Dissimilarity is measured as 1 minus Sorensen's Index, where Sorensen's Index is computed as the number of species that are common between the pixel and the region to which it belongs divided by the average alpha within the region.

Range Restriction

The Range Restriction Index is based on a comparison of the area over which the species is found relative to the entire study region. It is intended for continental or global scale analyses and should include a mask file to mask out water areas for land species or vice versa for marine species. The index ranges from 0-1 with high values indicating that the majority of species present at that location have restricted ranges. Note that the index is continuous and does not rely on a threshold area to define range restriction. For more information on the Range Restriction Index, see the section titled **How it Works** in this chapter.

The Planning Tab

The Planning tab offers an initial set of interventions that will inevitably grow with future versions. The current version offers:

- Constraints and incentives. This provides the ability to assess the impacts of existing and proposed reserved areas, along with tools such as tax incentives, for redirecting the course of change. These interventions are integrated with the change prediction process.

- Infrastructure modifications. This panel provides the ability to specify a set of major infrastructure changes by indicating the names of existing infrastructure layers and the dates they become effective. In addition, new infrastructural components can be developed by specifying the end-points and allowing the system to develop the least-cost engineering routes.

- Corridor development. The corridor planning tool develops biological corridors based on species suitability models, weighted development suitability, weighted conservation value and protected lands. Target corridor width and the number of branches can also be specified.

The Constraints and Incentives Panel

The Constraints and Incentives panel allows you to specify an incentive/constraint map for each of the transitions in the model. Constraints and incentives are handled in a unified fashion. Values of 0 on the map are treated as absolute constraints while values of 1 are unconstrained and consequently have no impact. Values less than 1 but above 0 act as disincentives while values greater than 1 act as incentives.

The way the constraints and incentives feature works is that the transition potentials associated with each transition are *multiplied* by the incentives/constraints map.

Important Note

Use incentives and disincentives with care. Small changes can have huge impacts. In normal use, you will have areas of absolute constraints (0), areas where normal transition potentials apply (1) and a few areas that may be slightly above or below 1 (e.g., 0.9 to 1.1).

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7. Whittaker, R.H. (1972) "Evolution and measurement of species diversity", *Taxon*, 21, 213-251.

The Planned Infrastructure Changes Panel

This panel allows you to enter the names of major road developments and the year they become effective. The Change Allocation panel of the Change Prediction tab checks this list with each stage of the prediction and adds each new road when the date of the active stage is equal to or greater than the infrastructure date.

The Corridor Planning Panel

This panel is used to build biological corridors. The primary inputs are Boolean maps of the two terminal regions and a habitat suitability map. Optional inputs include a development suitability map, a conservation value map and a protected lands map. The habitat and development suitability maps, as well as the conservation value map should all be measures on a 0.0-1.0 scale. The protected lands map is one where all non-zero values are treated as protected.

If either of the development suitability maps or conservation value maps is included, a weight needs to be specified. Habitat always has a weight of 1 and the weights of the other two can be from 0.0 to 1.0.

The final parameters that need to be specified are the ideal corridor width and the number of branches. Note that there is no guarantee that the target width will be achieved – it may simply not be available. The first branch is by definition the best route. Successive branches are of lower quality. See the section titled **How it Works** in this chapter on how the corridors are built.

The Marxan Panel

Two Marxan panels within Land Change Modeler Planning tab are meant to interface with the Marxan software. Marxan is freeware developed at The University of Queensland intended for conservation planning. Marxan provides techniques for reserve system design and performance as well as tools for developing multi-use zoning plans for natural resource management. Marxan can be used to identify areas that meet biodiversity targets, taking into account minimum costs.

Marxan is not provided with IDIRISI but can be downloaded for free from The University of Queensland website at: http://www.uq.edu.au/marxan.

How it Works

1: The Evidence Likelihood Transformation Utility

The Evidence Likelihood transformation requires two inputs:

1. A Boolean map of areas that have gone through the transition being modeled (this can easily be created from the Change Analysis tab).

2. A categorical variable or a continuous variable that has been *binned* into classes (such as with the STRETCH module).

The procedure looks at the relative frequency of pixels belonging to the different categories of that variable within areas of change. In effect, it asks the question of each category of the variable, "How likely is it that you would have a value like this if you were an area that would experience change?"

2: Explanatory Variable Test Procedure

The explanatory variable test procedure is based on a contingency table analysis. For qualitative variables, it uses the native categories of the variable to test association with the distribution of landcovers in the later landcover map. Quantitative variables are *binned* to 256 categories in order to conduct this test. This is a quick but imprecise fishing tool. The quantitative measure of association used is Cramer's V. A high Cramer's V indicates that the *potential* explanatory value of the variable is good, but does not guarantee a strong performance since it cannot account for the mathematical requirements of the modeling approach used and the complexity of the relationship. However, it is a good indication that a variable can be discarded if the Cramer's V is low. The *p* value expresses the probability that the Cramer's V is not significantly different from 0. Note that this assumes that all pixels are independently sampled and have no spatial dependence in their values. Thus a low value of *p* is not a good indicator of a variable's worth, but a high value is a sure sign that it can be rejected.

3: Use of the Multi-Layer Perceptron (MLP) for Transition Potentials

When calculating transition potentials, LCM launches MLP in a special *automatic* training mode. Automatic mode monitors and modifies the start and end learning rate of a dynamic learning procedure. The dynamic learning procedure starts with an initial learning rate and reduces it progressively over the iterations until the end learning rate is reached when the maximum number of iterations is reached. If significant oscillations in the RMS error are detected after the first 100 iterations, the learning rates (start and end) are reduced by half and the process is started again.

All other parameters of the MLP are used by LCM at their normal default values. However, LCM does apply special modifications to the outputs. Since specific transitions are being modeled, LCM masks out of the transition potentials all cases that do not match the *from* case of any specific transition. For example, if the transition being modeled is from forest to agriculture, values will only exist in pixels that were forest to start with.

4: LCM's Hard Prediction Procedure

The hard prediction procedure used by LCM is based on IDRISI's multi-objective land allocation (MOLA) module. IDRISI looks through all transitions and creates a list of host classes (classes that will lose some amount of land) and a list of claimant classes (classes that will acquire land) for each host. The quantities are determined from a run of the MARKOV module. A multi-objective allocation is then run to allocate land for all claimants of a host class. The results of the reallocation of each host class are then overlaid to produce the result.

The module that performs this work is CHGALLOC, which is an internal module that does not exist in the menu system. When running, it will report the number of passes which is identical to the number of host classes.

5: LCM's Soft Prediction Procedure

Soft prediction is simply an aggregation of the transition potentials of all selected transitions. Two aggregations are provided – the maximum transition potential and the logical OR of transition potentials. The latter is the default and assumes that if a location has the potential to transition because of more than one claimant class, it is even more likely to change than if a single claimant wants it.

6: Calculation of the Range Restriction Index

The formula for the Range Restriction Index is as follows:

$$RRI = \frac{\sum_{i=1}^{n}\left(1-\left(\frac{range\_area}{total\_area}\right)\right)^{2}}{Alpha\_Diversity}$$

where alpha diversity is expressed as richness (the number of species) and the total area is the total area of the image minus any masked areas.

7: How Biological Corridors are Built

LCM builds corridors using a cost distance procedure. The first step involves an aggregation of the various suitability/value maps. In general the effect is such that conservation value increases suitability for the corridor while development value decreases it (although only in unprotected lands).

Once an aggregate suitability map has been created, the suitabilities are converted to frictions and a cost distance is calculated from one of the terminal regions. A least-cost path is then run from the other terminal region back to the first. After this, a second cost distance is run from the least-cost path, after which it determines the mean relationship between cost distance and spatial distance to determine a cost threshold to use in constructing the corridor.

If additional branches need to be built, the suitability of already selected corridor areas is reduced to zero and the process is repeated.

References

Eastman, J. R., L. Solorzano and M. Van Fossen. "Transition Potential Modeling for Land-Cover Change." In GIS, Spatial Analysis and Modeling, edited by David J. Maguire, Michael Batty and Michael F. Goodchild, 357-385. Redlands, CA: ESRI Press, 2005.