

Chapter 8

CREATING HISTORICAL RANGE OF VARIATION (HRV) TIME SERIES USING LANDSCAPE MODELING: OVERVIEW AND ISSUES

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8.1 INTRODUCTION

Simulation modeling can be a powerful tool for generating information about historical range of variation (HRV) in landscape conditions. In this chapter, I will discuss several aspects of the use of simulation modeling to generate landscape HRV data, including (1) the advantages and disadvantages of using simulation, (2) a brief review of possible landscape models, and (3) the pitfalls and limitations of the simulation approach. This information provides a reference for planning, preparing, implementing, and interpreting HRV simulations and their results.

Before proceeding, it is probably best to define some major terms that will be used in this section. HRV time series refers to spatial or tabular data that represent landscape characteristics over time (e.g. percent coverage of a Douglas-fir vegetation type on a 500 km² landscape at 10-year intervals for 1000 years). While HRV can represent any ecosystem element at any scale, this section will only discuss HRV landscape dynamics and landscape structural and compositional characteristics. Size, arrangement, and pattern distribution of patches describe landscape structure, while landscape composition is often described by the relative abundance of ecosystem features across the spatial domain (e.g. percent area by cover types).

Modeling terminology can also be confusing, so it is important to define important terms as well. Model parameterization is the quantification of the major parameters required as input to the model. Parameters are static variables, such as smoke-emission factors or duff bulk densities, with values estimated by the user or model author. Parameters for some models are emergent properties (dynamically simulated output) for other models; fire-return interval, for example, is an input parameter in landscape succession model (LANDSUM) (Keane et al. 2006), but it is an explicitly simulated output variable in FIRESCAPE (Cary 1997). State variables are those dynamic variables explicitly simulated by a model, such as stand carbon or fuel loading. Model initialization involves quantifying state variables from plot data, geographic information system (GIS) maps, and previous simulation results to begin a simulation. Model execution refers to running the model to create output to analyze. The output contains predictions or estimations of response variables that, in this chapter, are the variables directly represented in the HRV time series.

How to create HRV time series

To understand the complexity involved in generating simulated HRV time series, it is important to know the general steps involved for the creation of a simulated HRV data set (Fig. 8.1):

1 State your objective. The most important step in the entire process is to succinctly state the objective of your HRV analysis so that you can properly select the best response variables and the most appropriate model.

2 Select response variables. The decision of which variables to include in the HRV time series will make model selection and parameterization easier, but a long list of response variables will limit the number of available models and complicate an HRV analysis.

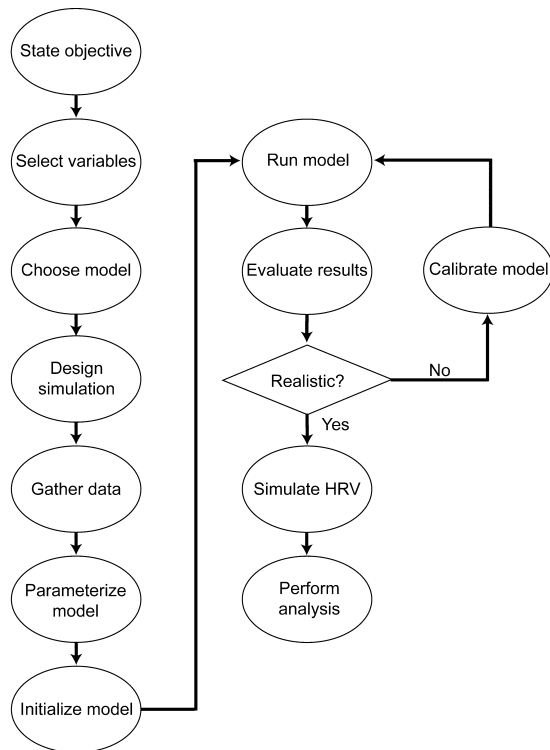


Fig. 8.1 The steps involved in creating HRV time series using landscape simulation modeling.

3 Choose your model. Selecting the right model is also an important step (Keane et al. 2009), so use experts to help decide the most appropriate model for a particular application; ensure that the input requirements for the model are available; find sufficient expertise to run the model; and make sure there are adequate computer resources to execute the model.

4 Design the simulation. Decide important simulation specifics such as the landscape extent (i.e. project area), pixel size, buffer width, length of the simulation, and output-reporting interval.

5 Gather data. The availability of data is critical to quantify parameters and starting conditions for the entire simulation area. If data are not available, literature searches, local experts, and statistical modeling can help quantify those missing parameters.

6 Parameterize model. Analyze collected data to quantify parameters for direct input into the model and be sure to document all sources of information used to quantify each parameter.

7 Initialize model. Many modelers use data that describe current conditions as a starting point in the model (e.g. a digital stand map classified to vegetation type could be used to initialize a landscape simulation).

8 Execute model. The model should be run again and again to be sure that all parameters and initial conditions are entered into the model correctly and to address all error statements and warnings.

9 Evaluate results. Always examine model outputs in detail to determine if the model is computing believable and realistic answers.

10 Calibrate model. Check simulation results against field data to ensure realism; if unrealistic predictions are generated, adjust parameters and initial conditions to get more reasonable answers, especially for those parameters with high uncertainty, such as those quantified from expert opinion and other relevant studies. (Repeat steps 8 and 9 until satisfied with results.)

11 Simulate HRV. The simulated HRV time series can be generated once the user is content with model behavior; these time series should be compared again against data to address validity.

12 Perform HRV analysis. Use the simulated HRV time series in land-management applications (e.g. change in similarity between simulated HRV time series and contemporary landscapes can be computed using Sorenson's index) (Keane et al. 2009). The analysis of HRV time series is the same whether it was created from simulation or empirical chronosequences.

8.2 SIMULATING HRV: THE GOOD AND THE BAD

Simulation modeling may provide the only vehicle for creating HRV time series with sufficient depth and detail for comprehensive land-management applications. However, simulation models should be used with great caution because all models are oversimplifications of reality and cannot represent the full range of landscape processes that influence HRV statistics. Understanding the strengths and weaknesses of the simulation approach is important to properly interpret and analyze HRV time series.

Advantages of the simulation approach

One good thing about simulation modeling is that it can produce spatially consistent HRV time series across relatively large areas. Although most simulation models may have limited accuracy, their real strength is that they have great precision: the models simulate disturbance and vegetation development processes in the same way across large regions and over long time spans. This helps to ensure that all ecosystems will be simulated at the same level of detail so that HRV time series are not biased toward certain ecosystems (providing they are represented in the same detail in model design).

The simulation approach also allows the generation of multiple time series reflecting alternate landscape histories, so that range and variation statistics can be computed across a wider envelope of historical and potential future conditions. Several climate-change scenarios, for example, could be simulated to generate a potential landscape-composition time series under future climates. For example, to predict future conditions, the succession simulation could include exotics to address their influence on historical departures and management actions, which can then be compared against the simulated HRV time series.

Another advantage is that simulation extrapolates limited field data consistently across large regions and over long time periods. Empirical data with inconsistent spatial or temporal coverage can parameterize landscape models, which can then simulate ecological processes to extrapolate parameter values across entire regions. A mountainous landscape, for example, may have limited fire-history data for a small portion of the

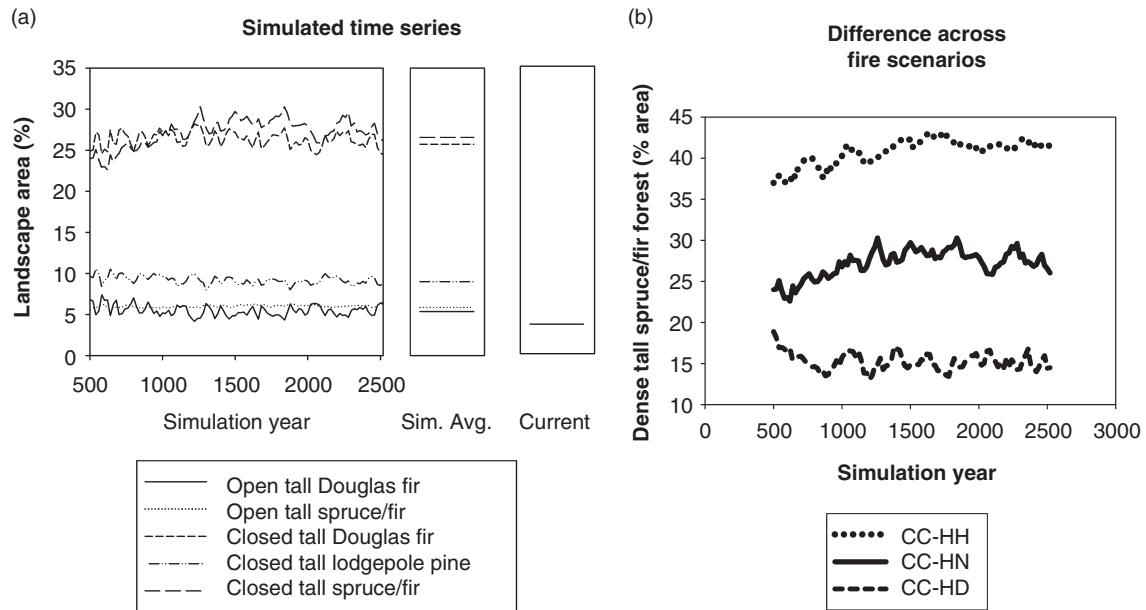


Fig. 8.2 An example of a simple five response variable (cover type extent) HRV time series for a mountainous subalpine Montana, USA landscape and its comparison to current conditions (from Keane et al. 2008).

area, but these data can parameterize fire history across the entire area based on biophysical factors.

Simulation models also generate many types of output to describe historical variation for a multitude of management objectives. For example, landscape models can generate maps of fire frequency and severity (Fig. 8.2) that can be compared with current fire atlases to estimate indices of departure in terms of fire regime (Keane et al. 2004). Fuel characteristics can be assigned to simulated vegetation types to generate historical chronosequences of fuels. The results can then be compared with current fuel maps to evaluate changes in fire hazard. Moreover, multiple output maps created by simulation can be merged to compute an integrated measure of HRV, as all output maps were created in the same context.

Landscape models can perform intermediate analyses to output additional HRV response variables. For example, landscape models can include wildlife-suitability statistical models to evaluate HRV of wildlife-habitat indexes. Models can also be modified to incorporate the latest research findings and computer technology, including improvements in model algorithms, parameters, initial conditions, and testing procedures, making them a highly adaptable tool for HRV generation.

Another advantage of simulation modeling is temporal depth. Creating deep temporal time series only requires additional years of simulation; deep temporal time series increases the number of observations, making analysis statistics more meaningful and powerful (Steele et al. 2006). Moreover, deep time series overcome issues of temporal autocorrelation by creating output at time intervals that are long enough to minimize correlation. Deep series are also long enough to ensure that the spatial properties of a fire regime are fully realized, which is especially difficult to evaluate in long fire-return-interval landscapes using empirically derived spatial chronosequences (Pratt et al. 2006).

Weaknesses of the HRV simulation approaches

Box and Draper (1987) said, "all models are wrong, but some are useful." This is the major drawback of all simulation approaches. It is impossible for a modeler to build a model that includes all the landscape and ecosystem processes that affect those variables selected to represent the HRV time series for several reasons. First, knowledge concerning the important processes and

their linkages is often inadequate. Second, as model complexity increases, instability, computational requirements, input parameters, and interpretability increase to unrealistic levels. Lastly, the modeler's knowledge, experience, and ability often limit complex simulation designs. There is always a trade-off between model complexity and tenability. Empirical modeling approaches often yield the most accurate answers, but they are limited in scope, often data intensive, and incapable of directly simulating complex interactions. Mechanistic modeling approaches include greater detail in simulating ecological processes, making them more robust and comprehensive; these models, however, can be inaccurate, difficult to use, and somewhat unstable due to the increased complexity (Keane & Finney 2003).

There is often a lack of sufficient expertise and input parameter data to parameterize and execute the model. Land-management agencies with inadequate modeling expertise on staff may have to rely on outside experts to run, summarize, and interpret model output. A credible model used improperly is useless for HRV analysis, and model results that are interpreted inappropriately could also result in unwise management. It would be inappropriate, for example, to use a 1-km pixel resolution, landscape model to determine silvicultural thinning locations.

It is difficult to test and validate many landscape models because there are few spatial historical time series that are temporally deep and in the right context for comparison with model results (Keane & Finney 2003). Desirable characteristics for validation data include (1) compatible format and units with model output, (2) extensive time period representation, and (3) consistency across the entire landscape. Because comprehensive spatial historical data are rare, many modelers turn to the validation of a landscape model's modules or algorithms as a way to verify that the model is producing realistic results. Stage (1997) performed an extensive validation of succession parameters for the Columbia River Basin successional model (CRBSUM) landscape model (Keane et al. 1996a) using the forest vegetation simulator (FVS) stand growth model (Crookston & Dixon 2005) and found greater than 80% agreement. Keane et al. (2002) compared simulated fire area and pattern statistics from a 1000-year LANDSUM run to the historical fire atlas created by Rollins et al. (2001) and found >85% agreement with fire size but poor agreement with fire shape (<30%).

No single model will satisfy the varied demands of management, so compromises in simulation design must always be made. The best model might not be the most useful because (1) few people know how to run it, (2) there may be insufficient computer resources (software, hardware requirements) to run it, and (3) there may be insufficient field data for input parameter approximation. Most HRV simulation projects are designed around the people responsible for their completion. The following sections were written for them.

8.3 LANDSCAPE SIMULATION MODELS

Many types of landscape models generate HRV time series of landscape characteristics. One class of landscape models, called landscape fire succession models (LFSMs) (Keane et al. 2004), simulate the linked processes of fire and succession in a spatial domain. Although the complexity of spatial relationships of climate, vegetation, fire ignition, and fire spread may vary from model to model, all LFSMs, by definition, produce time-dependent, geo-referenced results in the form of digital maps or GIS layers. Keane et al. (2004) reviewed 44 LFSMs and then classified them into similar groups based on scale of application, simulation detail, and fire-modeling approaches. He et al. (2008) and He (2008) described and classified many forest landscape models that simulate natural and man-caused disturbance in forested landscapes. Baker (1989) examined several landscape change models and grouped them into whole, distributional, and spatial landscape models depending on the level of data aggregation. Mladenoff and Baker (1999) present details of some landscape models, and Gardner et al. (1999) provides a review of spatial fire spread and effects models. Perry and Millington (2008) also present a summary of disturbance and succession modeling efforts.

Several existing landscape models provide examples of the diverse approaches used to simulate landscape, climate, and fire dynamics. At the complex end, FIRE-BGC integrates the mechanistic FOREST-BGC biogeochemical model (Running & Coughlan 1988) with the FIRESUM gap-process model (Keane et al. 1989) to simulate climate-fire-vegetation dynamics in a spatial domain (Keane et al. 1996b). LANDIS is a diameter cohort process model that evaluates fire, climate, insects, windthrow, and harvest disturbance regimes and their effects on landscape pattern and structure

(He & Mladenoff 1999, Mladenoff 2004), with fire effects indirectly simulated at the stand level based on age-class structure, and succession simulated as a competitive process driven by species life history parameters. Roberts and Betz (1999) used life history parameters or vital attributes of Noble and Slatyer (1977) to drive succession in their polygon-based LANDSIM model, which simulates fire effects at the polygon level without a fire-spread model. The DISPATCH model of Baker (1999) stochastically simulates fire occurrence and spread based on the dynamically simulated weather, fuel loadings, and topographic setting, and then simulates subsequent forest succession as a change in cover type and stand age. Miller and Urban (1999) implemented a spatial application of fire in the Zelig gap-process model (Burton & Urban 1990) to assess the interaction of fire, climate, and pattern in Sierra Nevada forests. Any one of the models could be used to estimate HRV, but most are research models developed for exploring dynamic landscape interactions.

Most land managers find simple, parsimonious models preferable for HRV generation because they are easier to use, simpler to learn, quicker to execute, and more straightforward to interpret. More simplistic approaches include the SIMPPLLE model (Chew et al. 2003), which uses a multiple pathway, state-and-transition approach to simulate succession on landscape polygons and a stochastic approach to simulate fire. This same theme can be found in the FETM (Schaaf et al. 2004), VDDT (Kurz et al. 1999), and LANDSUM (Keane et al. 2006) models. Other similar approaches and models were used by Wimberly et al. (2000) for the Pacific Northwest and Keane et al. (1996a) for the interior Columbia River Basin.

8.4 SELECTING THE MOST APPROPRIATE MODEL

Selecting the most appropriate model for HRV generation is no trivial task since there are many models available and every model is different in design, input and output requirements, and detail of simulation. One important HRV model selection criterion is that the model should be spatially explicit, which means it should explicitly simulate spatial processes across a landscape (often called landscape or spatial models). The spatial simulation of ecosystem processes ensures that simulated landscape structural and composition variation includes those sources of variation due to

spatial factors. Karau and Keane (2007) found that output variation increased as the spatial extent decreased, indicating that without the explicit representation of spatial processes, stand-level models will tend to underestimate the range and variation of historical landscape dynamics, resulting in higher estimates of departure for current landscape conditions (Keane et al. 2009). A spatial model is vital for comprehensive HRV analysis because HRV is somewhat meaningless without a spatial context. Nonspatial landscape models, such as VDDT (Beukema & Kurz 1998), will underestimate variation in HRV response variables, thereby compromising the integrity of HRV time series.

The selected model should provide output that can be used directly in management HRV applications. If the model does not output fuels, for example, then estimating the HRV of fuel loadings will be difficult. Many managers overcome this problem by making the HRV variable in question an attribute of the entities or state variables that are simulated or by modifying the model to output the desired attributes. For example, fuel loadings can be assigned to each vegetation type (variable output by the model) to quantify wildland fuel HRV time series. Managers should evaluate the list of output variables from the models to determine which best fit their specific application.

The design, detail, and resolution of the simulation model are also important factors to evaluate when selecting a model for HRV application. The ecological processes integrated in the model, and their detail of representation, are critically important to insightful HRV generation. The greater the simulation complexity, the greater the variation will be in HRV response variables (Keane et al. 2009). Here are additional suggestions:

- 1 Select a model that simulates spatial processes at the right resolution. Spatial models that simulate fire spread at 30-m pixel size or less, for example, are the most appropriate for quantifying HRV for small landscapes.
- 2 Select a model that simulates the important processes that influence the selected response variables. Users should try to match model state and other simulated variables with desired output; if climate-change impacts must be assessed, then select a model that explicitly includes climate in its simulation.
- 3 Avoid models that require input parameters that are too difficult to quantify. Data input requirements for some models are so specific that they are difficult, if not impossible, to measure or estimate by managers. For

example, maximum stomatal conductance as required by Biome-BGC (Thornton et al. 2002) is a parameter that few can accurately measure but is an important and sensitive parameter in the model.

The selection of the most appropriate model boils down to one single factor – the resources available to run the model. There must be knowledgeable, experienced people available to successfully run, or learn to run, the model and interpret model output. If there are few people available locally on staff, then it may help to look for other specialists, organizations, or businesses to perform these tasks. Computers used for HRV simulations must also be capable of executing the model in terms of hardware requirements (memory, disk space, processor speed), software necessities (ancillary analysis software, statistical packages), and network capacity (ability to transmit large amounts of data). Model design is probably the least-used selection factor for many managers because it requires considerable knowledge about simulation science and model specifications to effectively compare the vast array of models.

8.5 SIMULATION ISSUES AND LIMITATIONS

Simulation modeling is a complex process with many challenges in its implementation. A thorough knowledge of these limitations is critical for a comprehensive evaluation of HRV analysis results and implementations.

Parameterization

Perhaps the most important task in conducting HRV simulations is the accurate estimation of input parameters. There are often insufficient ecological data across an area for parameterization so data synthesis and modeling are often required to extrapolate existing data across the entire simulation landscape. Parameters can be approximated from many sources, and are listed here in order of preference:

1 Measurement. The actual measurement of input parameters across the simulation landscape produces the most credible simulation results; it is important to sample the full range of the parameter to minimize extrapolation into unsampled space.

2 Literature. A review of the literature to evaluate the parameter values measured on other landscapes by

other studies may provide a suitable alternative, but special care must be taken to ensure that the context of the measurement best fits the simulation landscape. Several literature syntheses of important model parameters are available (Korol 2001; Hessel et al. 2004).

3 Meta-modeling. Models can estimate parameters for other models. Stage et al. (1995), for example, used a growth and yield model (FVS) to estimate growth parameters for a gap model.

4 Iterative modeling. A parameter is approximated, input into the model, and then the model is executed to generate results that are compared to a reference to determine if the reference agrees with the simulated results. If not, changes to the parameter should be made incrementally until the results match the reference.

5 Expert opinion. A parameter is approximated by a group of experts in a systematic fashion, based on their past experience.

6 Default. Often, a modeler will prepare a sample model application for demonstration purposes, and use parameter values generated from the default input files.

7 Best guess. Sometimes, the only option is just to guess at the value based on past experience and consultation with modelers, and then use iterative modeling to calibrate the guess.

Technically, the author of each landscape model should conduct an extensive sensitivity analysis of their model's parameters to identify the importance of each so that detailed measurements or literature searches are not made on minor parameters, or best guesses are not used for the most important parameters.

Accurately estimated model parameters do not always ensure simulations with high accuracy or realism. There is always a disjunct between model design and model parameterization. Keane et al. (2006), for example, found fire regimes in mountainous settings were simulated incorrectly when fire-return-interval parameters were quantified from tree fire scars taken from topographic settings that experienced frequent fires (e.g. flat areas). The detail in the simulation model will never capture the detail of environmental factors that created the field evidence from which parameters are quantified. As a result, it is difficult to realistically simulate disturbance or vegetation development without building overly complex models that would be difficult to parameterize and inefficient to run for large landscapes over long simulation periods.

Autocorrelation

Most simulated time series are autocorrelated in space and time, as are real landscapes (Ives et al. 2003). Any part of a simulation landscape ultimately depends on the surrounding area (Turner 1987), and the condition of a landscape in one year greatly depends on the landscape composition and structure during the previous years (Reed et al. 1998). Moreover, the area covered by one vegetation type relates to the extent of all other vegetation types; an increase in one type must result in the corresponding decrease of one or more vegetation types on the landscape (Pratt et al. 2006). Autocorrelation may be considered part of HRV and therefore may not be important (Keane et al. 2011), but many statistical techniques require minimization of autocorrelation in response variables (Steele et al. 2006).

Temporal autocorrelation can be minimized by selecting a reporting interval that is long enough to reduce temporal autocorrelation but short enough to provide a sufficient number of observations to perform a valid statistical test and to adequately represent the variation. This reporting interval varies by landscape depending on fire frequency and succession transition times, but informal investigations suggest that 20–50 years would suffice for most landscapes (Pratt et al. 2006). A new set of statistical analysis tools may be needed to compute an index of departure that is both useful to land management and satisfies the assumptions of HRV analysis by minimizing direct effects from autocorrelation (Keane et al. 2011).

Scale

Using the same temporal and spatial extent to evaluate landscapes across large regions will introduce bias into the computation of HRV statistics because the scales of climate, vegetation, and disturbance interactions are inherently different across landscapes (Morgan et al. 1994). Karau and Keane (2007) found that simulated HRV chronosequences of landscapes smaller than 100 km² had increased variability in landscape composition due to the spatial dynamics of simulated disturbance processes. This is why HRV approaches are inappropriate when applied on small areas such as stands. A Douglas-fir stand historically dominated by ponderosa pine, for example, may appear to be outside HRV, but if it is within a 100-km² landscape composed primarily of ponderosa pine, it will certainly be within HRV. On the other hand, when evaluation landscapes are large (>500 km²), it is often difficult to detect significant changes caused by ecosystem restoration or fuel treatments implemented on small areas (Keane et al. 2006).

There is an optimum landscape extent for HRV simulation, but this optimum depends on subtle differences in topography, climate, and vegetation across large regions. Karau and Keane (2007) computed optimal landscape sizes for flat and mountainous areas in central Utah under various fire-return intervals and simulation resolutions and found this optimum to differ by topography and geographical area (Table 8.1). This optimum also changes with simulation spatial resolution, which is important because coarser

Table 8.1 Optimal landscape sizes (km²) for a mountainous and flat landscape for three different fire regimes – historical fire frequencies, half the historical fire frequencies, and double the historical frequencies. Simulations were done at four pixel resolutions (30, 90, 300, and 900 m) (see Keane et al. 2008 for more details).

Fire Frequency	Resolution			
	30 m	90 m	300 m	900 m
Mountainous landscape				
Half	87	103	104	111
Historical	90	99	105	108
Double	100	103	101	106
Flat landscape				
Half	107	73	72	81
Historical	84	104	97	98
Double	100	105	101	99

Note: There are no results for the 0.01-km² average fire size and the 900-m resolution simulation combination.

simulations require shorter execution times and less computer resources, making them more desirable for managers.

The input parameters more accurately represent the temporal depth of an HRV simulation than the length of the simulation (number of simulation years). Values given to parameters are usually derived, directly or indirectly, from field data, and these data often represent a small slice of time. Therefore, the simulated historical variation may not always represent the range of conditions needed to maintain healthy, resilient ecosystems. Given the age spans of some organisms used to quantify HRV (e.g. trees are often used to estimate fire histories), it is difficult to obtain comprehensive historical data over static climates and stable biophysical conditions. Therefore, the range and variation of most ecological characteristics tend to become greater as diverse climates are represented in the historical time series, resulting in a possible inflation of acceptable range and variation. The challenge, then, is to use an HRV time span supported by historical field data while also being representative of short-term future climate regimes.

Simulation complexity

The complexity of simulation models can have a major influence on both the creation of an HRV time series and the subsequent comparison of historical dynamics to current conditions. In general, output from complex mechanistic models tends to have higher variation than output from simplistic models. However, Keane et al. (2008) found that complex state-and-transition models with a large number of states had more elements to compare with current conditions and, as a result, the simulated variation of landscape elements was lower than in a simpler state-and-transition model, mainly because the large number of near-zero values for many states tended to lower departure estimates (Pratt et al. 2006). Departure estimation is best when succession pathway complexity is somewhat equal across all simulation landscapes and few states are rare on the landscape (Keane et al. 2011).

The design and detail of landscape models also affects HRV time series. Inadequate HRV simulation results will occur when critical processes are left out of the simulation model. For example, the lack of mountain pine beetle simulation in a landscape fire-succession model used to simulate HRV on lodgepole

pine landscapes may create historical time series that underestimate ranges and variation of lodgepole pine successional stages (Logan et al. 1998). Moreover, the detail of disturbance simulations also influences HRV simulated time series: simplistic cell-automata, fire-spread models, for example, may generate fire perimeters that are completely different when compared with perimeters simulated by complex vector spread algorithms (Keane et al. 2004).

An unfavorable side effect of HRV simulation modeling is that the range and variation of simulated response variables include the variation caused by uncertainty in model predictions. As mentioned before, it is nearly impossible to validate landscape models to quantify accuracy and error rates because of the lack of suitable spatial data. As a result, the simulated variation also includes undesirable and unquantifiable sources such as unintended stochasticity, model flaws, inadequate parameterization, and oversimplifications. It is important that modeling efforts have access to extensively sampled landscapes to create an extensive validation database that assesses unwanted sources of variation.

Model equilibration

The equilibrium models often used in HRV simulations may require long simulation times to come into equilibrium (Keane et al. 2006). Along with the input parameters, initial conditions often influence the time it takes for a model to reach equilibrium conditions. It is important to approximate the time to equilibrium for HRV simulations by graphically examining the time series and visually assessing when the initial conditions do not influence the simulated response variable. All HRV observations prior to this time should be removed from the time series, or the simulation should be executed again with output generated after this time. Pratt et al. (2006) estimated that at least 250 years were needed before the LANDSUM model came into equilibrium.

Using current landscape conditions to initialize historical landscapes can often be inefficient on two levels. First, the current landscape often contains too many patches, making simulation times longer and needlessly complex (Keane et al. 2006). Second, current landscapes are often so departed from historical conditions that it takes excessively long times to reach equilibrium. Moreover, exotic vegetation types that occur

on the current landscape are often not represented in historical parameters, resulting in inappropriate HRV time series. Pratt et al. (2006) found that creating neutral initial landscapes composed of the most dominant vegetation type was the most efficient for HRV simulations.

Edge effects

One of the major problems in defining simulation landscapes is that the landscape edges create artificial boundaries across which spatial processes cannot traverse. Areas near the edge of the landscape, for

example, have a limited number of surrounding pixels from which a fire can spread into them. Spatial processes, such as fires, cannot immigrate into the simulation landscape, resulting in decreased occurrence near landscape edges. This problem is exacerbated by biophysical factors that are directional vectors that act on many ecosystem processes such as fire, seed dispersal, and windthrow (e.g. wind direction and slope). Pixels near the direction from which the wind originates (upwind), for example, have a lower probability of burning than those downwind (Keane et al. 2002) (Fig. 8.3). Some modelers try to mitigate this problem by “wrapping” the landscape – fires that burn off one side of the landscape burn onto the landscape from the

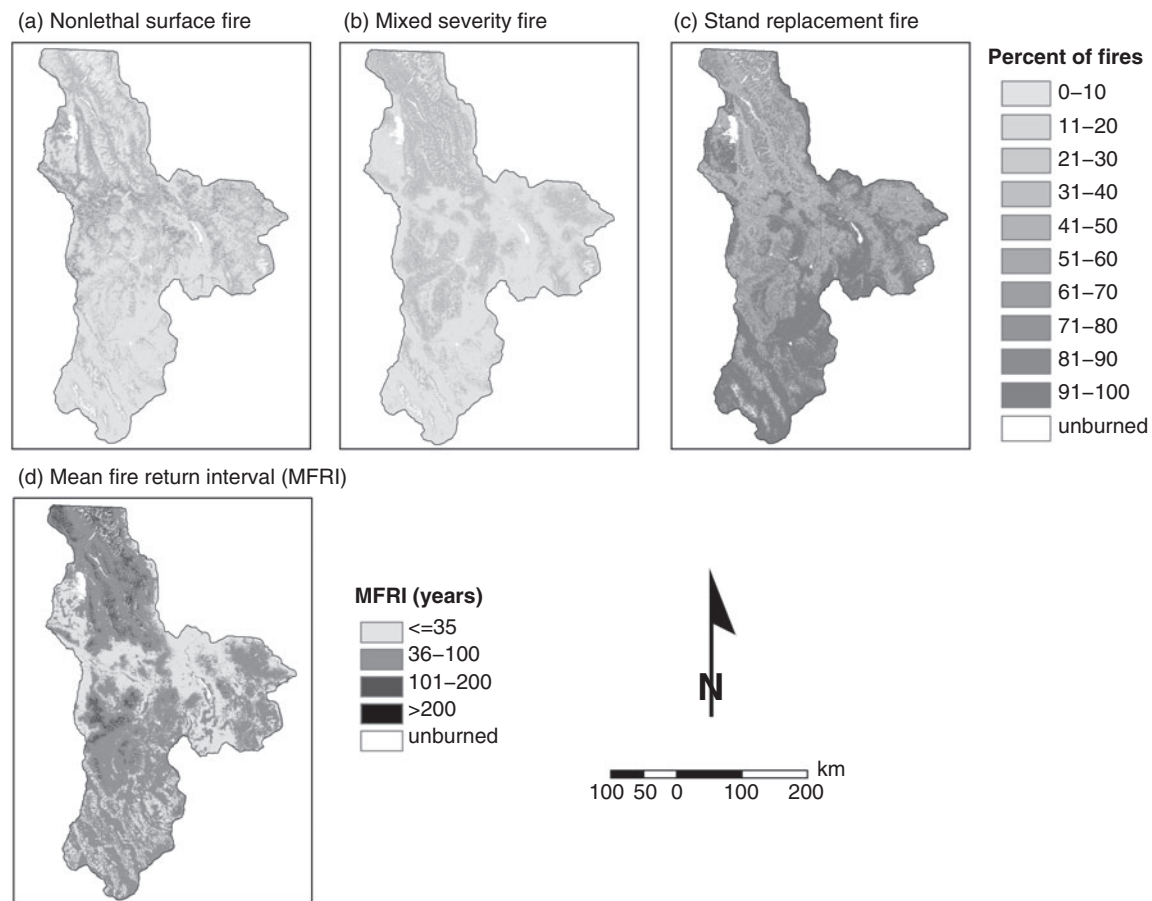


Fig. 8.3 Fire-regime maps produced by the LANDSUMv4 simulation model for the Northern Rockies region (from Pratt et al. 2006). Maps show the proportion of total fires that are (a) nonlethal surface fires, (b) mixed severity fires, and (c) stand-replacement fires. The mean fire-return interval (MFRI in years) is shown in the last map (d).

other side. This solution is inappropriate for many HRV simulations because topography, wind, and vegetation near one edge are not the same as on the other side of the landscape.

The best way to mitigate the edge effects is to surround the simulation landscape with a buffer (Fig. 8.3). To create a buffer, make the simulation landscape larger and then stratify the simulated output by the buffer and the context area. The LANDFIRE prototype project attached a 3-km buffer area around each 20 000-ha context area to create the simulation landscape (Pratt et al. 2006). The buffer should provide an adequate source for fires to immigrate from the windward and upslope side of the landscape. Each landscape is unique, so buffer width may differ for each setting. Modelers should always inspect fire-regime maps to determine if the buffer is large enough to minimize edge effects within the context landscape, keeping in mind that simulation time increases exponentially as landscapes get larger.

Landscape orientation and shape

The shape of the landscape is an important factor in the simulation of landscape dynamics. Fire frequencies in long, thin landscapes, for example, tend to be underestimated because simulated fires rarely reach their full size. Even with a large buffer, simulated fires spread quickly across thin context landscapes and burn only a fraction of its full size. Keane et al. (2002) found fire frequencies were approximately 20–40% less in long landscapes with high edge. Many managers like to use watersheds to define simulation landscapes, but watersheds are often long and linear with high edge, making them somewhat undesirable for HRV simulation. The best shapes are squares, rectangles, or circles that are large enough to contain both the buffer and context landscapes.

The directional orientation of the simulation landscape is also important. Long, thin landscapes that are oriented perpendicular to the wind direction will have far less burned area over time than the same landscapes oriented parallel to the wind (Keane et al. 2002). The orientation is especially important if watersheds define simulation landscapes because elongated watersheds that are positioned at right angles to the wind direction will tend to result in significantly less fire and narrow HRV time series.

Replication versus simulation time

Since most landscape models contain stochastic properties (i.e. probabilities are used to simulate some ecological processes), it is often suggested that the model be executed multiple times to quantify the variation of results due to the stochasticity inherent in the probability functions (Fig. 8.4). Repeated execution of the model is important in HRV simulations, especially in landscapes with rare disturbances, because it is possible that rare, large fires at the tail of the fire-size distribution may never be simulated. The inherent stochastic variation in simulated results should be considered part of the HRV and should probably not be averaged.

An alternative for many HRV simulations is simply to extend the simulation run, adding more simulated years to ensure adequate representation of disturbance regimes. Instead of simulating 10 replications of 1000 years, for example, one could simulate 10 000 years in one run. The length of the simulation also depends on the output interval, which is selected to minimize autocorrelation and to ensure adequate response variable sample size.

Simulation time versus real time

There is a common misconception that long-term simulation model HRV outputs are inappropriate because the simulation of fire and landscape dynamics occurred while unrealistically holding climate and fire regimes constant (Keane et al. 2006). This would be true if the objective of the fire modeling were to replicate historical fire events. However, the primary purpose of HRV modeling efforts is to describe variation in historical landscape dynamics, not to replicate them.

Simulation modeling allows the quantification of the entire range of landscape conditions by simulating the static historical fire regime for long time periods (e.g. thousands of years) to ensure all possible fire ignitions and burn patterns are represented in the HRV time series: long simulation periods ensure more fires are simulated on the landscape, resulting in better HRV estimates. In contrast, HRV time series from empirical historical records will tend to underestimate variation of landscape conditions because there are a limited number of fire events. The model input parameters represent the actual temporal context, while the simulation time represents the

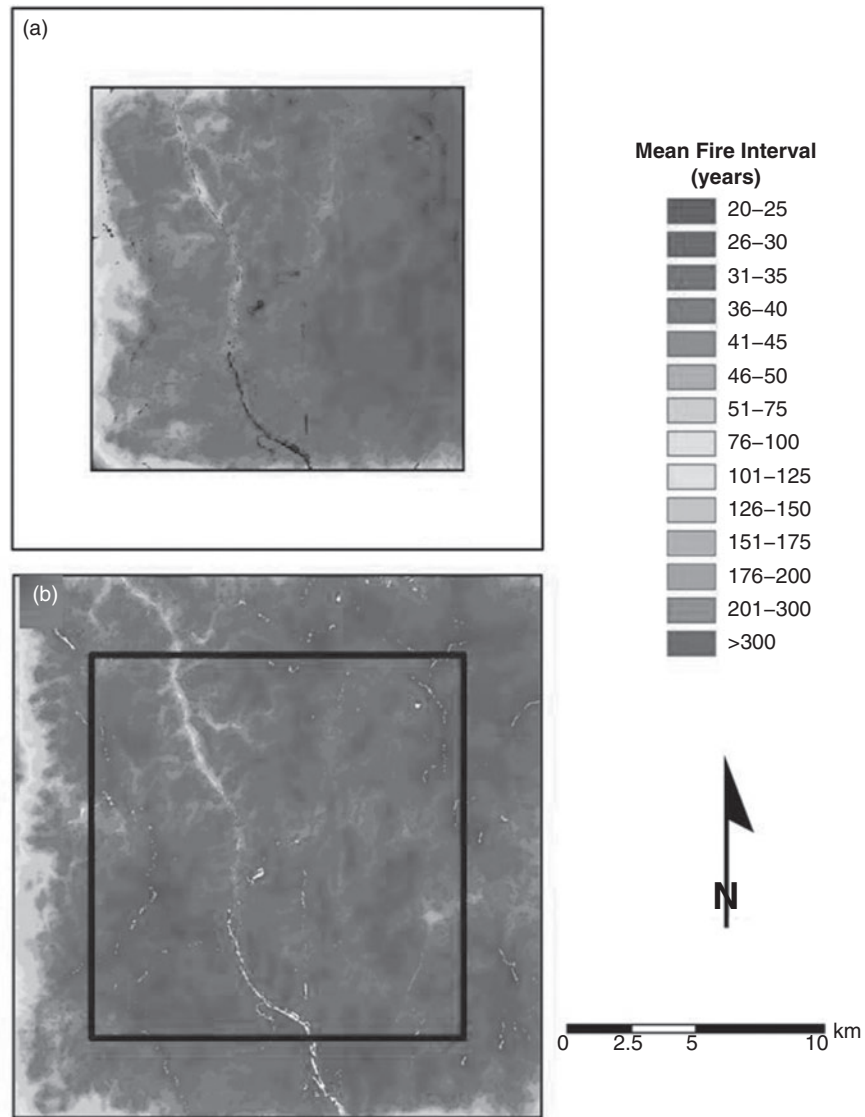


Fig. 8.4 An example of fire-regime simulation results showing the edge effect on fire frequency across the simulation landscape. (a) Fire frequency without a landscape buffer and (b) fire regime for the same landscape with a 3-km buffer. Please refer to Colour Plate 2.

length of time needed to adequately capture the range and variation of historical conditions. Because the time slice represented by model parameters often represents only four or five centuries, it may seem that only 500 years of simulation are needed (Fig. 8.5). However, the sampled fire events that occurred during

this time represent only one unique sequence of the fire starts and growth that created the unique landscape compositions observed today. If these events happened at different times or in different areas, an entirely different set of landscape conditions would have resulted.

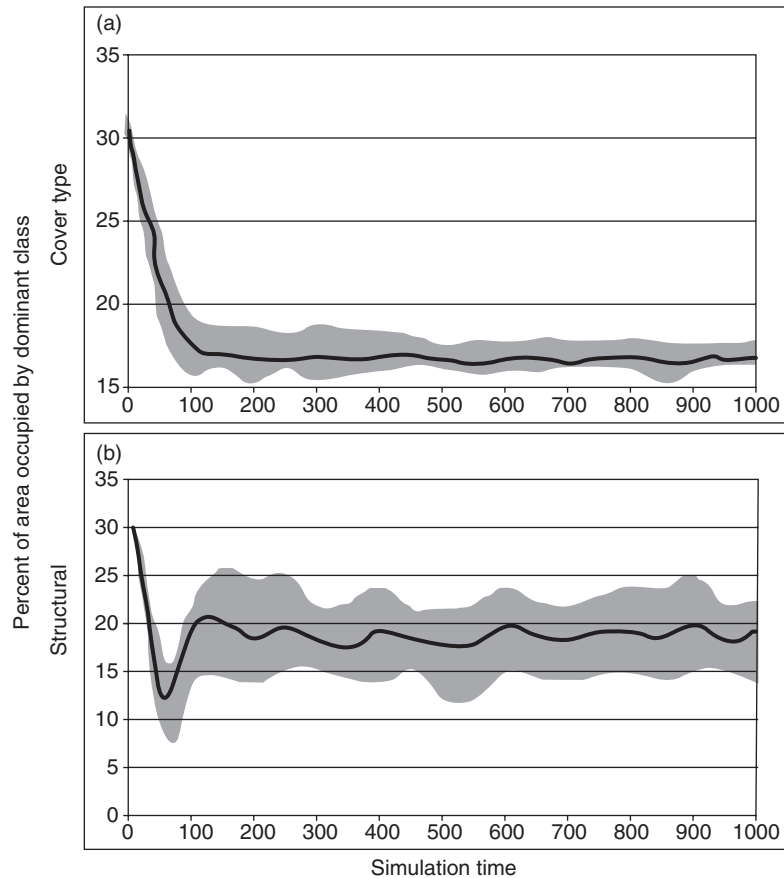


Fig. 8.5 Range of results for 20 LANDSUM model runs showing the inherent stochastic variation in predictions of percent landscape for (a) the dominant cover type and (b) structural stage.

8.6 CONCLUDING THOUGHTS

Much of HRV landscape modeling is about balancing realistic simulations of ecosystem dynamics with the often opposing goal of computational and logistical efficiency. This compromise becomes more important as simulation landscapes increase in size and complexity and as management issues expand in scope and scale. Simulation execution times tend to increase exponentially with increasing landscape size, but larger simulation landscapes are logistically simpler to prepare and produce better simulation results. There is no right way to simulate HRV, but there are many wrong ways. It is important that local experts review parameters, intermediate output, and results to ensure

realistic results. HRV simulations get easier with increased experience in simulation modeling.

Simulation modeling is a technology that will see more use in land management in the coming years. Costly and resource-intensive data surveys and field campaigns will become more difficult in the future with declining budgets, limited personnel, and dwindling expertise. And, as issues such as climate change become more complex and expand in geographic scope, the design and use of empirical approaches becomes more complicated and expensive. However, field data will continue to be absolutely essential to future simulation modeling efforts. The real challenges in the future will be to (1) design models that contain sufficient detail to simulate complex ecological interactions

that are also useful to managers; (2) adapt field data inventory and monitoring projects to collect those data that can be used to build, parameterize, initialize, and validate models, as well as provide sufficient information to solve management problems; and (3) provide sufficient training and assistance to managers in using landscape models.

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