



TELSA

*Tool for
Exploratory
Landscape
Spatial
Analyses*

TELSA: Tool for Exploratory Landscape Scenario Analyses

Model Description, Version 3.3

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Executive Summary

The Tool for Exploratory Landscape Scenario Analyses (TELSA) was originally created by ESSA Technologies Ltd. in cooperation with the BC Ministry of Forests and the US Forest Service. TELSAs is a spatially explicit, landscape-level model of vegetation dynamics. The purpose of the model is to assist resource managers and planners assess the consequences of alternative management scenarios at the landscape level over time frames of decades to centuries. The model simulates vegetation succession, natural disturbances, and management.

Alternative scenarios are assessed using a number of performance indicators that include areas annually affected by natural disturbances and management activities, as well as indicators of vegetation composition (cover type distribution, seral stage distribution, etc.) and landscape structure (patch size distribution, amount of interior habitat, amount of edge, etc.). Combined, these indicators provide information required to evaluate the impacts of alternative management strategies and assumptions about natural disturbances on biodiversity, and other resource indicators such as timber, landscape health, and habitat supply.

Adaptive landscape management requires tools that assess the outcomes of alternative management actions. The intended use of TELSAs is strategic scenario exploration: interested users can explore how management strategies will interact with natural succession and disturbances to alter the composition and structure of landscapes. Wildfires and other disturbance events that affect vegetation dynamics are inherently unpredictable. The model acknowledges this uncertainty and uses stochastic simulations of multiple scenarios to provide estimates of the mean, range and variability of the changes in the selected performance indicators.

The model is not an optimisation tool, it does not assist in tactical decision making, nor will it make decisions for resource managers. Instead, we envision it to assist in the planning process by providing biologically and ecologically reasonable projections of the outcomes of alternative scenarios. Trade-offs among scenarios are evaluated by comparing the indicators of interest. Choices among management alternatives are based on the ability of scenarios to meet guidelines, constraints, or desired future conditions, such as maintaining interior forest habitat or target distributions of seral stages.

TELSAs represents vegetation succession as changes in species composition and structural stages of polygons. It thus provides information about stand structure and composition, which is immediately relevant for the analysis of wildlife habitat and other resource indicators. Succession is defined in pathway diagrams for each potential vegetation type in the landscape. These diagrams describe the transition times between successional classes and for each class, the probabilities of disturbance by insects, fire or other agents. The same pathway diagrams also define the impact of management actions on vegetation structure and composition.

TELSAs has been applied successfully to simulate vegetation dynamics, natural disturbances, and management actions in areas of dry interior forests (near Kamloops, BC), northern coastal forest (near Smithers, BC), northern boreal forests (north of Edmonton, Alberta), sagebrush steppe and woodlands in Eastern Nevada, and mixed grass prairie in Saskatchewan. Other applications are in progress in several areas of the western US.

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1.0 Introduction

The Tool for Exploratory Landscape Scenario Analyses (TELSA) is a strategic, landscape-level planning tool that can be used to project scenarios of management actions and natural disturbances onto a landscape, and to assess the long-term spatial and temporal effects on a range of performance indicators.

The model projects vegetation dynamics and management activities in space and time, and illustrates trends in several indicators associated with alternative scenarios. TELSAs facilitates the evaluation of alternative management options by assessing their impacts on several performance indicators.

1.1 Model objectives

The objectives in the development of TELSAs were:

- to build a spatially explicit, strategic landscape-level planning tool that assesses the effects of natural disturbances, management actions, and vegetation dynamics on a series of indicators;
- to include indicators on the characteristics of the vegetation distribution in space and time (seral and age-class distributions, patch size distributions, fragmentation, etc.), other indicators of management (such as the area affected annually by each of the management activities and by natural disturbances), and some indicators of the implications of these disturbances on wildlife habitat, biodiversity, and other non-timber resource values; and
- to address stochastic events — such as natural disturbances — by simulating multiple Monte-Carlo runs of the same management scenario, in order to obtain results of the range and variability of possible scenario outcomes.

1.2 Model limitations

TELSA is intended to be a strategic tool, focussing on predicting trends or patterns of change in the performance indicators in response to management actions and natural disturbances. The strength of the model is that it can project a range of management scenarios over large areas and over time. The large size of landscape-units used by the model, however, means that the model will need to evaluate spatial changes at a relatively coarse scale. The model is not intended to generate results that can be used at the tactical planning stage (e.g., positioning of landings, choices of seasonal operating areas, etc.). It cannot provide and should not be expected to replace expert opinion, field investigations, tactical models, or stand-level growth and yield models such as TASS (Mitchell 1975), and FVS (Prognosis; Wykoff et al. 1982), that project detailed tree or stand characteristics.

TELSA is not intended to be used for Timber Supply Reviews (TSRs) or to provide input into the determination of the Annual Allowable Cut. TSRs are usually conducted for larger areas than are reasonably addressed by the analyses conducted with this model, and they may account for many factors, which are not included in the model such as the changing ability of mills to use small wood or social and economic concerns.

TELSA is not designed to make management decisions. While certain functions of the model may incorporate a set of rules to schedule sequences of events or to distribute management actions in space

and time, the model is not an optimisation tool (i.e., the intent is not to have the model search for the “optimum solution” given a set of constraints). The model projects natural and human disturbances onto a landbase over large areas, and systematically evaluates the consequences of these actions and events on a set of indicators. These indicators can be used to assess the projected impacts of management scenarios. It is up to the user (or user group) to develop and run several scenarios, and to use these results to compare and contrast the implications of different scenarios. A planning team can then use these results to assess trade-offs and to develop appropriate long-term management plans.

TELSA is not designed to make decisions on area definitions such as planning zones or protected areas. As described below, these and other subjectively based designations will need to be delineated in advance by the planning teams.

TELSA may help identify complementary management actions that need to be implemented together to achieve desired results (e.g., partial cutting and access management). A productive environment for the application of TELSAs to a landscape planning exercise will require some commitment from both the planning and management team to objectively evaluate different scenarios based on projected impacts on the performance indicators.

As with all models, care should be taken in the interpretation of model projections and output, as these will necessarily reflect the data quality and assumptions used to calibrate the model. Expert opinion must be used to calibrate the model where empirical information is not available. The model calibration and assumptions should be reviewed periodically.

Development of the TELSAs model is ongoing, and the approaches, model interface, calibration and simulation options may change as the model develops and is user tested.

1.3 Recent changes

Version 3.3

1. A new feature called “Polygon Forcing” is now available. This feature allows users to force state class changes for specific LU polygons at specific time steps in a simulation. It is being used to incorporate external models of petroleum industry developments in the boreal forest such as seismic lines and pipe lines.
2. Polygons now track both their absolute age and the state based age. Age rules for pathway transitions are now applied to the state based age to ensure that pathways developed in VDDT behave in the same way when imported into TELSAs.
3. As with VDDT ‘Keep Relative Age’ is now a flag that can be added to each disturbance pathway.
4. Users can now choose to randomize the order of operational unit management priorities between Monte Carlo simulations.
5. Temporal multipliers can now be applied to polygon based attributes.
6. Spread distance for contagious disturbances is now sensitive to the condition of the polygon being spread into.
7. Users can now optionally add spatial autocorrelation to the type of pathway used in a disturbance event as it spreads to similar neighbours.
8. The probability that a polygon will be a disturbance initiation site is now weighted by its area.

Version 3.2

1. Disturbance spread is now sensitive to polygon condition such that spread is more likely towards polygons with higher disturbance probabilities than other neighbours of the source polygon.
2. Disturbance spread is now optionally sensitive to topography. Users can define spread multipliers for disturbance spread as a function of the slope between the source and target polygons.
3. Users can import “wind zone” maps into the model and define wind direction distributions for each wind zone (see point 4 below).
4. Disturbance Spread is now optionally sensitive to wind direction. Users can define spread multipliers as a function of the difference between the wind direction at the time of disturbance (calculated from 2 above) and the direction of spread.
5. Disturbance Groups can now be defined as contagious over time. These disturbance groups spread using annual spread distance distributions instead of probabilities. Users must define source polygons at initial conditions, the spread distance distribution, the infectious time span and any disturbances or management activities that may turn off infection.
6. The study area set-up tool now reads the polygon centroid co-ordinates into the database for use by the new disturbance spread algorithms.
7. Users can import “initiation multiplier” maps into the model. These maps are used to initiate sources of contagious disturbances at the beginning of a simulation. They are also used to modify Disturbance initiation probabilities for specific polygons on the landscape.
8. Users can simulate polygon-based attributes. These are attributes of individual polygons that change as a function of polygon state, ageing, and disturbance history. Users define the rules as to how polygon attributes change over time.
9. The algorithm that determines management unit sizes within a user-specified range has been changed so that the distribution of management unit sizes is more uniform.
10. The TSD value for each polygon is now randomised between 0 and 40.
11. **Bug Fixes:**
 - a. Non-independence in Management Unit Sizes between Monte Carlo Simulations when management unit size ranges were relatively narrow.
 - b. Failure to complete a second activity for management systems with overlapping age ranges.
 - c. Failure to conduct certain activities within an activity group with multiple activities.

Version 3.1a

1. In anticipation of simulating the influence of topography on disturbances, DEM data can now be loaded into the TELSAs Database.
2. The graph display tool now prints data and graphs directly to MS Excel worksheets. Output from various runs and variables can now be printed on the same graph.

Version 3.1

1. Different trend multipliers can now be loaded and applied to different planning zones.
2. Different sequences of temporal multipliers can now be applied to different Monte Carlo simulations in the same run. These sequences can either be loaded from VDDT as MCM files or created in TELSAs.
3. The number of disturbance incidents in a group can now be constrained either by total area disturbed, as was the case in version 3.0, or by the size class distribution defined by the user. This prevents the artificial occurrence of many small incidents in highly fragmented landscapes.
4. Specific minimum and maximum size limits can now be defined for natural disturbance groups.
5. “Reporting Zones” — regions of specific reporting interest that can be created for study areas at any time. These regions have no influence on model behaviour.
6. Planning zone maps can now be deleted through the map preparation interface.

2.0 Model Overview

The application of TELSAs in a strategic landscape planning process involves several stages and will usually involve contributions of experts from differing backgrounds. The four main stages in the analysis process (Figure 2.1) are:

1. initial model setup;
2. scenario definition and selection;
3. simulation runs; and
4. analysis of model results.

Steps 2 through 4 would usually be repeated in a series of iterations as the results of the first analysis inspire additional questions and suggestions for further scenarios.

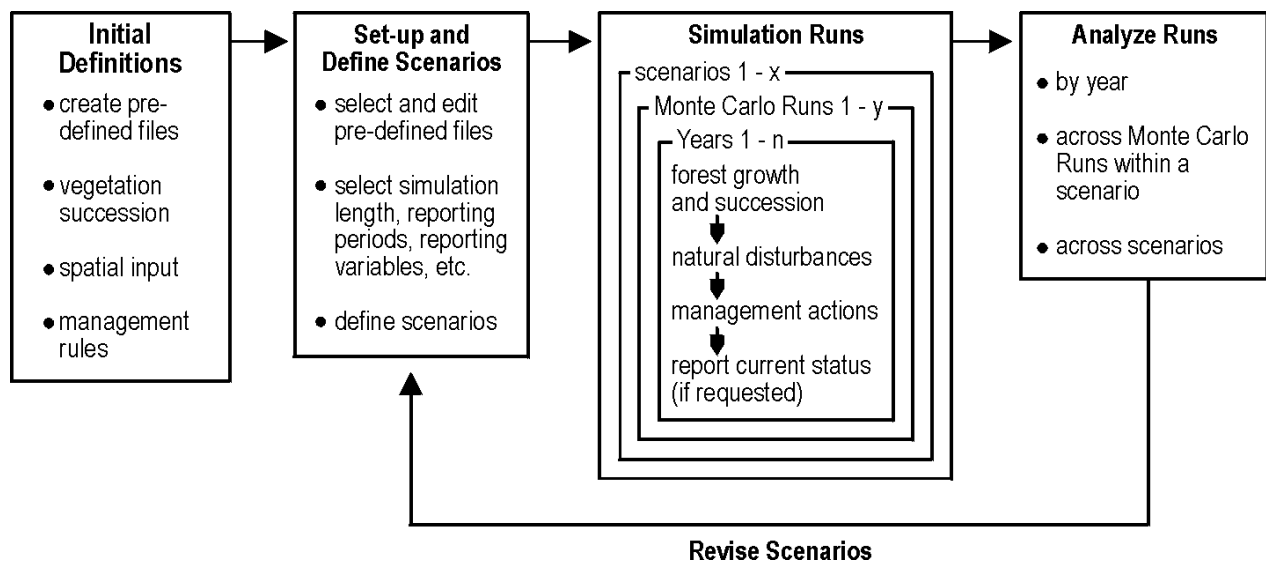


Figure 2.1: The four main stages of the analysis using TELSAs. Initially, users must create a series of input files, which will be used as “pre-defined files” for future model runs. The second main step is to set-up the model and define the scenarios to be simulated by selecting from and editing existing files. Various scenarios can then be simulated, each with multiple Monte Carlo runs if required. Results are analysed and summarised for spatial and non-spatial indicators.

2.1 Initial model setup

TELSAs requires several rule sets and model parameters that describe ecological processes (e.g., succession, disturbances), management information (e.g., silvicultural systems definitions, operational units), planning information and constraints (e.g., green-up requirements, zoning specifications) and other information that will be required during the analysis.

Experts from various fields have provided information that has been compiled in a set of database tables. These tables will be accessed during a TELSAs run. One design objective for TELSAs was to provide access to all information required for a landscape-level analysis while at the same time not expecting every user to be an expert in all areas. Thus, a group of ecologists, entomologists and fire experts can develop the rule base for the description of vegetation succession and natural disturbances, while silviculturists can use the information on forest succession to describe how stand-level silvicultural treatments affect subsequent stand dynamics. A planning team can then use this information to explore different scenarios of management activities and natural disturbance regimes without having to be experts in vegetation dynamics.

Files prepared during the initial setup stage are a resource that combines the knowledge of many experts. The files contain many of the basic assumptions required for the landscape-level analysis. They can be edited and revised at any time, however, to explore alternative assumptions or when improved data are available.

TELSAs is a spatially explicit model using a vector-based GIS approach. TELSAs requires some information in a map-based format. Prior to conducting a landscape analysis, several GIS layers must be available to the model. Examples include vegetation cover information and management system designations.

TELSAs simulates the dynamics of an entire landscape by representing the dynamics of individual spatial entities, which are referred to as “minimum polygons.” These can be aggregated to management units, a form of “treatment-blocks” (see Section 3.1 for more detail). During the spatial setup, the user defines a set of parameters, which are used to divide the existing vegetation cover polygons into minimum polygons. This process is fully automated, using some ArcView-based tools. The resulting map yields spatial entities within a range of sizes that are used for all subsequent simulation analyses. The user has the option to prepare multiple versions of this map, using different criteria for the partitioning and aggregation processes.

2.2 Scenario definition and selection

A model “scenario” represents a set of model parameters and rules describing the processes that affect the vegetation dynamics of the landscape. These include:

- successional pathways;
- natural disturbance regimes;
- management system definitions;
- management system assignments;
- management constraints and guidelines;
- planning zone designations;
- spatial information about initial conditions; and
- other data.

To define scenarios, the user selects a specific combination of the available parameter sets or defines one or more new sets of assumptions. For example, a user who wants to explore alternative assumptions about management constraints and guidelines would explore multiple scenarios modifying the management assumptions. A second user interested in the impacts of alternative assumptions about future natural disturbance regimes would set up scenarios with different parameter sets about fire probabilities.

TELSA simulates some stochastic processes, such as fire ignition and spread. The intended use of the model is to explore the range of possible outcomes for each scenario, as explained in more detail elsewhere in this model description. It is therefore necessary to have the option to run multiple Monte-Carlo simulations of the same scenario. Monte-Carlo simulations of one scenario use the same set of assumptions but differ in the randomly drawn parameters that determine the outcome of probabilistic events and processes.

In preparation of a model analysis, users must first define those scenarios they want to simulate. They then define the sequence in which the scenarios are to be analysed, the number of years each scenario is to be simulated, the number of Monte-Carlo simulations for each scenario, and the reporting time step for landscape-level indicators (Figure 2.1).

Once all run conditions are specified, the user submits the run-stream instructions to the model.

2.3 Simulation runs

TELSA reads the run-stream instructions and executes the simulation of multiple model scenarios in sequence. For the analysis of an entire landscape, scenario analyses are “overnight” runs.

For each scenario, TELSAsimulates the requested number of years, e.g., a 100-year simulation, in annual time steps. The model simulates vegetation succession, natural disturbances, salvage operations in response to natural disturbances, and other management activities. The model reports the requested information to output tables and files. In every time step, the model reports the events of the year, such as the information on polygons affected by disturbances or management. In every reporting time step (e.g., every 25 years in a 100-year simulation), the model saves the complete database that describes the state conditions of all those polygons in the landscape whose conditions can change from the initial conditions.

The model repeats simulations of each scenario as many times as requested by the user. Each Monte-Carlo simulation will have a different random number seed thus representing alternate outcomes of the stochastic processes in the model. Upon completion of a set of Monte-Carlo simulations, the model starts the next scenario.

2.4 Analysis of model results

Results of the model simulations are post-processed to obtain spatial and non-spatial summaries of the information. A graphical user interface allows the user to view and print non-spatial statistics, such as the area affected annually by disturbances or management activities for the landscape as a whole or for user-selected biogeoclimatic subzones. The same interface is used to compare results of multiple Monte-Carlo simulations or to compare results of alternative scenarios. The analysis component of TELSAsalso reports age-class distributions, seral stage distributions, area statistics and many other indicators. A second graphical user interface, using a customised ArcView application, allows users to map various indicators at different points in time, and allows users to easily compare the spatial arrangement of these indicators for different scenarios, years, or Monte Carlo simulations. A third interface, using ArcView and its Spatial Analyst, can be used to calculate various spatial statistics on the landscape for different runs.

Each interface interacts directly with the databases that contain information on the entire landscape. This gives users maximum flexibility for queries and display of model results.

2.5 Summary of TELSAs components

TELSA represents a set of tools for the preparation, analysis and display of landscape-level scenarios. The main components of TELSAs are (Figure 2.2):

Database:

This Access database stores all relevant spatial and non-spatial information that define the initial conditions, the assumptions about the simulation runs, as well as the results from the simulation.

Database Editor:

A graphical user interface is used to access and edit information in the database.

VDDT:

The Vegetation Dynamics Development Tool (Beukema et al. 2002, Beukema et al. 1998) is used to define successional pathway diagrams and disturbance probabilities in a landscape. VDDT is a stand-alone tool, which has been developed to quantify assumptions defined in successional pathway diagrams. VDDT is not technically part of TELSAs, but information exported from VDDT simplifies the development of pathway and disturbance information required by TELSAs.

Vegetation Rule Translator (State Class Assignment Tool):

A graphical user interface is used to access the tool that translates the vegetation cover information into the successional classes defined in the successional pathway diagrams.

Map Preparation, Study Area & Spatial Scenario Setup Tools:

ArcView-based graphical user interfaces are used to prepare the spatial information required by TELSAs.

TELSA Main Model:

The main simulation model of TELSAs retrieves the information in the databases, simulates the vegetation dynamics, natural disturbances, and management actions in the landscape. It is designed to execute several runs in “batch-mode,” thus not involving interactions with the user.

Spatial Analysis Tool:

A graphical user interface and GIS are used to conduct the spatial analyses.

Map Display Tool:

A graphical user interface and GIS are used to display maps of the model results.

Graph Display Tool:

A graphical user interface is used to analyse, display and report non-spatial results of model simulations.

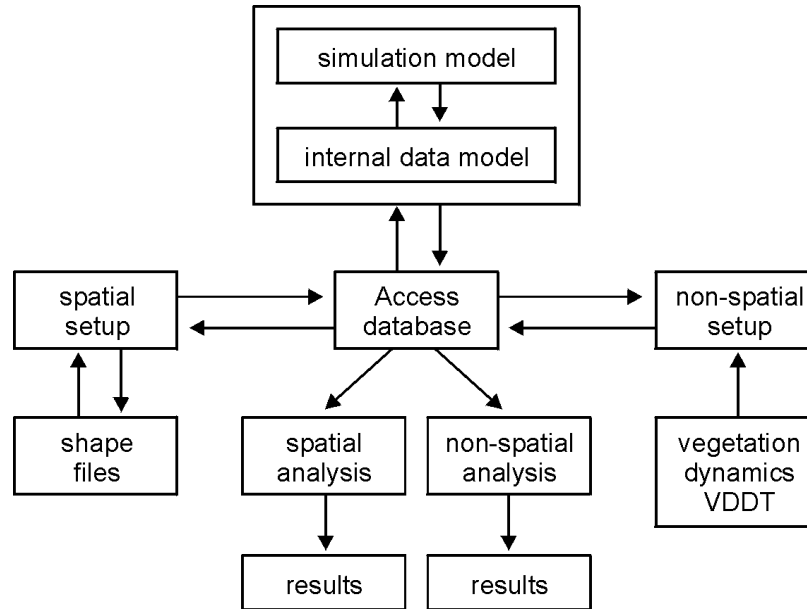


Figure 2.2: The main components of TELSAs.

2.6 Monte Carlo simulations

TELSA has been designed to address some of the uncertainties inherent in landscape-level forest dynamics. It is designed to assess the range of scenario outcomes through the use of multiple stochastic runs. The advantage of this approach is that it recognises that a specific set of management rules will yield a range of possible future outcomes, because of the impacts of natural disturbances. The potential disadvantage is that it could be necessary to make a large number of time-consuming runs to get a clear picture of the range of future conditions.

While it may be necessary to simulate many stochastic runs for some specific variables, it will be less necessary for aggregate indicators such as the distribution of seral stages or age-classes. The number of runs required will depend on the specificity of the measure. General and aggregate indicators such as patch size, connectedness, etc. will effectively be replicated within one run of the model across the spatial extent of the study area being simulated as well as over the years of the simulation. Thus for very aggregated indicators a very small number of runs will be needed. For very specific measures at certain times in certain locations it is likely that a much larger number of runs will be necessary.

Sensitivity analyses and other systematic exploration of the range of model outcomes will be required to gain experience with the model behaviour and the model properties.

2.7 Technical requirements

TELSA is designed to run on high-end Pentium-based personal computers. It requires a 32-bit operating system, such as Windows 2000 or Windows XP. It uses Microsoft Access 97, a relational database system, to store all database tables. Graphical user interfaces are written in Visual Basic (Version 6.0). The simulation model is written in C++ (Microsoft Visual C++ Version 6.0). Analysis and display of spatial information is performed with ArcView (Version 3.1 or later) and the Spatial Analyst.

TELSA requires at least 512 MB of computer memory (RAM). The amount of free disk space required will vary with the size of the landscape that is analysed and the number of simulation runs that are conducted. As with all spatially explicit models, a generous amount of free disk space is highly recommended.

3.0 Initial Setup

3.1 Spatial setup

During the spatial setup phase, the landscape is divided into a series of polygons of variable size. The smallest spatially explicit entity is a *minimum polygon*. These have a single set of unique fixed characteristics such as age, vegetation cover and structure. All other spatially explicit units are made up of groups of minimum polygons. No spatial data are available below the minimum polygon.

One level above the minimum polygon is the *management unit* (Figure 3.1). Each management unit consists of one or more *minimum polygons*. The management polygon is the smallest unit that will be considered in any given management activity. At any instant in time, each minimum polygon belongs to at most one management unit. In previous versions of TELSAs, management units were created only once, during the initial setup. Versions 3.0 and later create new management units each year using feedback on the current condition of the landscape. This ensures that only polygons of user defined age and structure are included as part of the same management units. When minimum polygons within a management unit are disturbed or have undergone management to completion, they are released and become potentially eligible for inclusion in other management units.

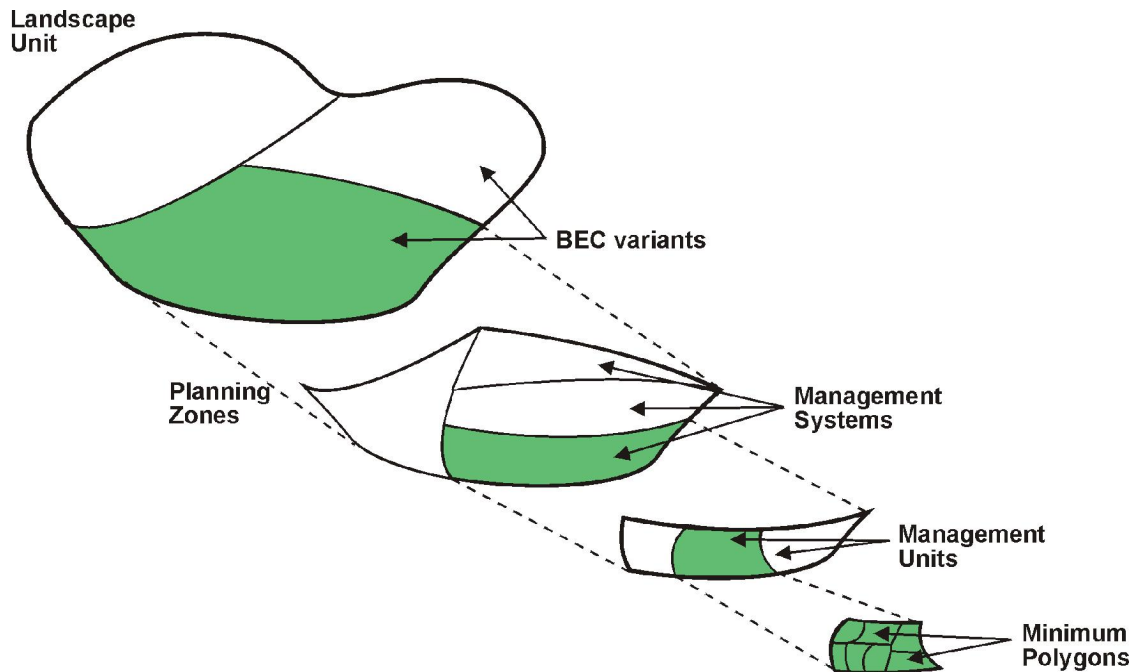


Figure 3.1: Spatially explicit entities in the landscape. A landscape is divided into BEC variants and planning zones. Each unique combination of BEC variant and planning zone contains one or more management units, which in turn is divided into one or more minimum polygons, the smallest spatially explicit entity.

Planning zones are areas within the landscape that share a particular set of constraints or other management-related rules (such as wildlife objectives, etc). These may be of any scale and can represent watersheds, wildlife management zones, riparian buffers, etc. **BEC variants** are the ecological stratification of the landscape. Management is assigned to unique combinations of these planning zones and BEC variants using one or more **management systems** to describe what activities should take place when. Management units are created based on this information.

Operational units (not pictured in the figure) also divide the landscape and are used to sequence management in different parts of the landscape as part of the harvesting algorithm. These are created using information regarding access routes, topographic barriers or other logistic considerations that influence the location and pattern of management. Each one can contain multiple management units, BEC variants, and planning zones, and can cross the boundaries of BEC variants and planning zones. Users can chose to randomize the sequence in which operational units are managed between Monte Carlo simulations.

Each management unit is wholly contained within an operational unit, planning zone and BEC variant, and is assigned to only one management system.

Minimum polygons are created at the beginning of the simulation as part of the spatial setup. The basic process to creating minimum polygons in the landscape by subdividing larger forest cover polygons is called **tessellation**.

3.1.1 Map preparation

The first step in the spatial setup phase is to add information about the various maps to the database. Three types of maps are required by TELSAs: Vegetation Cover, Planning Zones and Operational Units. In addition, the following maps can be used by the model: Digital Elevation, Wind, Reporting Zones, Initiation Multipliers and Roads. The Map Preparation Tool is an ArcView-based tool that assists in this information transfer. Every polygon in the landscape must belong to one operational unit and at least one planning zone.

For planning zones and operational unit maps, the process is quite straightforward. The Map Preparation Tool stores, in the database, the location and name of the map(s), the planning zones or operational units in each map, and, for the operational units, the management priority of each unit. In doing so, the tool also alters the dbf file associated with the map by giving it an extra column called "PZID" or "opUnitID," depending on the type of map.

Forest cover maps are more complicated. The Map Preparation Tool adds (or copies) a number of columns to the original dbf, including species codes, percent representation of the species, age, BEC variant, etc. that will be used by the State Class Assignment Tool (Section 3.3.3). In addition, the tool adds the polygons and the name and location of the map to the database.

Road maps are optional in TELSAs. The road map provides a system of roads in the landscape. As management occurs road segments are activated. Overtime, if left unused, roads become deactivated. Users can add an existing road map to the database and use the "road extender" to extend roads to minimum polygons.

Reporting zone, topographic, wind zone and initiation multiplier maps are also optional. These maps can be prepared at any time after the study area is setup. Reporting zone map preparation is similar to planning zone and operational unit preparation. Unlike planning zones and operational units however,

reporting zones can be defined for small or large regions and need not cover the entire landscape. When present, reporting zones allow users to analyse model output for these specific regions, (community watersheds for example), without having influence on the model behaviour.

Topographic information can be prepared for a TELSAs study area. Elevation information is used by TELSAs in when spreading disturbances from one polygon to another. Wind zone maps can also be imported into the TELSAs model. For each wind zone users can define a wind rose or frequency distribution of wind directions. This information is used to make the spread of disturbances from one polygon to another sensitive to wind direction. Initiation multiplier maps can also be prepared to increase or decrease the likelihood of a disturbance initiation based on external data such as lightning strike maps.

3.1.2 Tessellation

The purpose of the tessellation is to divide large landscape polygons into smaller units that can be used for simulating disturbances and for creating management units. This is done in a tool called the Study Area Setup Tool, and may be done on either the whole landscape map or on a subset of that map.

The Study Area Setup Tool operates on an overlay of one or more map layers. One map layer must be the forest cover map, which contains information about the forest cover polygons, and the BEC variants. Other map layers can include planning zones or operational units. The first step of the tool is to create a new map layer that contains a unique set of polygons whose boundaries have been created by the overlay of the maps. Thus, for example, long thin polygons can be created if a riparian zone map was used in this process.

These polygons then may be further subdivided using a Voronoi tessellation approach. First, the whole landscape is sprinkled with points. The user determines the spacing and the x-y variability of these points. Once the point set has been created it is used to create a set of basic polygons using the proximity function in ArcView. The map calculator function in ArcView and this Voronoi diagram are then combined to create smaller polygons. Polygons from the forest cover map that are smaller than a user-defined size will not be subdivided and new polygons will not be created if they would be smaller than a second user-defined size threshold. For example, suppose there are three forest cover polygons of sizes 1 ha, 4 ha, and 8 ha. The user specifies that forest cover polygons must be at least 3 ha before they can be divided and the newly created minimum polygons must be at least 2.5 ha. If by chance the tessellation would divide each polygon in half, the model would leave both the 1 ha and 4 ha polygons intact because the 1 ha polygon is less than 3 ha and the 4 ha one would have created two 2 ha polygons. It would create two new 4 ha minimum polygons from the 8 ha forest cover polygon.

Some polygons may have been designated as “non-projectable” in the “state class” table in the database. These indicate features such as lakes, roads, rivers, etc. that are not vegetated or whose properties will not change over time. In order to save time and space, these polygons, while they may be subdivided through map overlays, will not be tessellated.

The study area setup tool also creates a table of the distance (edge to edge) between pairs of minimum polygons. The model uses these distances when it checks for greenup constraints before constructing a new management unit. Pairwise distances are only listed up to a maximum distance specified by the user; otherwise the size of the database would be unmanageable. The user must specify a maximum distance that is at least as great as the maximum greenup distance they plan to use.

3.1.3 Spatial scenario setup

In TELSAs the assignment of management systems to management units is based on planning zone and BEC combinations. The sequencing of management across the landscape is based on operational units. Therefore, before the management units can be created, another ArcView-based tool must be used. This tool, called the Spatial Scenario Setup Tool, uses the Study Area Map created from the tessellation process, and any planning zone and operational unit maps that will be used in creating management units. It then looks at the overlays of these maps and creates a table in the database of all combinations of planning zones and BECs that occur in each minimum polygon, and the amount of area associated with these combinations. This step is needed for assigning management systems (see Section 3.2.1) before creating management units. The output of the Spatial Scenario Setup Tool is added to the “scenario polygon tables” in the database. Multiple spatial scenarios can be set up for the same study area, each using a different set of planning zones and operational units. This allows users to compare alternative ways of allocating management systems to the landscape.

3.2 Non-spatial setup

A large part of the initial setup of the model involves defining values that, while they may apply only to certain areas, are not spatially explicit. These values do not need to be redefined for every new map or simulation. They can be grouped into two main categories: management information and natural disturbance information, both of which are described in more detail below.

3.2.1 Management definitions

TELSA is designed to explore scenarios of landscape dynamics resulting from management actions and stochastic natural disturbances. However, both natural disturbances and management actions will also respond to changes in landscape conditions. The extent to which a management activity such as spacing is conducted depends in part on the area of eligible stands in the landscape. TELSAs contains sets of rules and constraints by which the model can determine, in each time step, which management activities to implement and where to implement them. With these rules, management actions are implemented in ways that are consistent with the current conditions in the landscape. Details on how the model actually applies the rules are given in Sections 5.3–5.5.

The management actions are defined using the following components:

1. A list of Management Activities defines which activities can be represented in the model. These can include prescribed burning, thinning, clear-cut logging, planting, site preparation, and others.
2. Certain activities can be grouped into systems of activities that are executed in sequence. Activity Sets define groups of activities, the stand age at which the activities are undertaken, and their temporal sequence. For example, an activity set could define that site preparation occurs between the ages of 0 and 5, followed by planting in the same age range, and partial cutting every 40 years after the age of 60. Every activity set must include the activity “release,” which determines when all activities for a management system are complete and the management unit can be dissolved (See section 5.5).
3. System Constraints define a size range, green-up criteria, and an age range that can be combined into a single management unit. Multiple system constraints may be defined in the database. For example, a set of system constraints could define that the management had to apply to areas between 5 and 10 ha, with a green-up age of 17 and width of 500 m, and that polygons that were no more than 40 years apart in age could be combined together into a management unit.

4. Activity sets and system constraints are combined to create Management Systems. Thus, a management system is defined by a set of activities, which should occur within a specified size range and meeting the given green-up criteria. Management systems are assigned to the unique combinations of planning zones and BEC variants discovered using the Spatial Scenario Setup Tool. Once management units are created, each management unit is assigned one management system.
5. A second set of constraints can be defined. These are ones that apply to a certain activity or group of activities, independent of a specific management system. These are called Activity Constraints. These constraints are based on a group of activities (e.g., all types of thinning, or all activities), planning zone, and BEC variant, and may include green-up conditions, area bounds or age bounds. For example, no clear-cuts (activity) are permitted in a any BEC in a protected area (planning zone), or clear-cuts (activity) must be at least x metres from a stand that is less than y years old in planning zone A .
6. The Activity Limit defines the maximum amount of a certain activity that can be performed in a given year in a given planning zone. For example, no more than x hectares or cubic meters will be clear-cut in a year or no more than y hectares will be planted in a year. These upper bounds provide an additional, optional way to constrain the scenarios in a simulation. Activity limits have a user defined tolerance level. This prevents the model from seeking out tiny polygons, “slivers,” such that it meets the activity limit exactly.
7. The Successional Pathway Diagrams define the impacts of an activity on vegetation dynamics. For example, “clear cut logging and planting” a stand of type x will result in a regenerating stand of type y (see Section 3.3 for further details). An activity must have a defined pathway in order to occur.

Several of these components define constraints or limits for application of the activity. Each of the constraint tables is defined for specific spatial and temporal domains (Table 3.1). In some tables, the information will be stratified by groups of BEC variants, activities, or planning zones, so that users do not need to re-enter the values for each member of the group.

Table 3.1: Summary of the constraints that can be predefined by planning zone, BEC class, activity, year, age or size. Note that a management system combines an activity set and a system constraint, and then is assigned to be part of specific planning zones and BEC variants.

Information	Planning Zone	BEC Variant	Activity	Year	Age	Size	Greenup
Activity set			X		X		
System constraint						X	X
Management system	X	X	X		X	X	X
Activity constraints	X	X	X		X	X	X
Activity limits	X		X	X			

Management occurs in three different places in TELSAs, and each has its own set of characteristics. Details about the differences are given in Sections 5.3–5.5. In all three cases, the management must be in the list of activities and must have one or more pathways defined in the successional pathway diagrams. Otherwise, there are several differences between the types of information that must be defined in each case (Table 3.2).

1. *Salvage (Section 5.3)*

The constraints, limits, and activity sets defined above are not applied to salvage. Salvage uses a separate set of user-defined rules, and has its own defined limit. Many of the salvage constraints are based on information about natural disturbances.

2. *Aggregated harvest areas (Section 5.4)*

These use the defined activity constraints (not including block size or greenup) and activity limits, but are independent of management systems.

3. *Management units / Standard management (Section 5.5)*

Each management unit has a management system associated with it, and uses all the defined components. A management unit must meet all conditions before the model can operate on it, thus ensuring that the most stringent constraints are always met.

Table 3.2: Difference between the three main types of management.

	Activity Set	System Constraint	Management System	Activity Constraints	Activity Limits
Management Units	x	x	X	X	X
Aggregated Harvest Areas				X ¹	X
Salvage				based on nat. dists	X

¹ Activity constraints for AHAs are only based on age, planning zone and BEC. Constraints on greenup and block size are ignored.

3.2.2 Natural disturbance definitions

The dynamics of natural disturbances, other than their effects on vegetation, are defined by the following components:

1. *Size class distribution*

Different disturbance groups create impacts of different sizes and different ranges of sizes. Users must define a size class distribution for each disturbance group in each BEC variant by telling the model what proportion of the disturbance events will be in each of six different size classes. The six classes are: 0–1 ha, 1–10 ha, 10–100 ha, 100–1,000 ha, 1,000–10,000 ha, 10,000–100,000 ha. This distribution is then used in the model to determine the number of incidences that would occur in each size class, given the predicted area to be disturbed (see Section 5.2). Versions 3.1 or later allow users to constrain the total number of incidents in a disturbance group by size class rather than by area. This prevents the artificial occurrence of many small incidents when landscapes are highly fragmented.

2. *Temporal pattern definition*

The area disturbed can vary widely between years in the natural world. Use of the temporal pattern allows users to capture some of this variability by entering annual multipliers for each disturbance group. These are then applied in the calculation of the area annually disturbed, by scaling the area calculated based on the current landscape condition. This multiplier can be greater than 1 to create higher than expected disturbance levels, less than 1 to create lower than expected disturbance levels, or equal to 1 to leave the expected disturbance level unchanged (i.e., if the variability is thought to be a function only of the landscape characteristics). Versions 3.1 or

later allow users to define different sets of temporal multipliers for different Monte Carlo simulations. These different sequences can either be loaded from VDDT or created directly in TELSAs.

3. *Trend multipliers*

Climate change or other factors can cause a long-term trend in the area that is affected by a disturbance. For example, global warming may increase the area burned in the long-term. The trend multiplier table can be used to enter multipliers to be used for each disturbance group in each year. These are then applied to the area that TELSAs would normally predict would get disturbed. Versions 3.1 or later allow users to define trend multipliers by planning zone. This option may be used to simulate situations such as efforts of fire in specific regions for specified periods of time. When planning zones overlap, the multiplier chosen will be determined by the planning zone priorities defined by the user.

4. *Size Limits*

Some users simulate management actions with the natural disturbance definitions. For these users, versions 3.1 or later now allow more deterministic control over specific minimum and maximum disturbance sizes.

5. *Preferential Spread*

Users can optionally define rules about how the spread of natural disturbances from one polygon to another is influenced by wind and topography. See section 5 for details on preferential spread algorithms.

6. *Contagion*

Certain natural disturbance groups can be defined as contagious over time and space such that a disturbance may spread slowly from one polygon to another over several years. This functionality is useful for simulating slower moving events such as the spread of invasive weeds. Users define the annual spread distance distribution of the disturbance, its contagious life span and any other disturbances or management activities (for example herbicide application) that may negate the contagion.

7. *Initiation Multipliers*

Initiation multipliers can be defined for natural disturbance groups to take into account external influences on disturbance starts. These may include locations of already contagious polygons at the beginning of a simulation for contagious disturbance groups or lightning strike data for fire.

The above components are combined into a single “Natural Disturbance Scenario.” If size class information is missing for any disturbance, that disturbance will not occur. If no information is entered for the multipliers, a value of 1 will be used. Details on how this information is used are given in Section 5.2.

Natural state transitions are distinguished from management actions in the database. The database contains a list of all possible transitions: natural or managed. A separate table then specifies which of these are “natural transitions.” Note that management actions can be simulated using natural disturbance rules if users wish to do so.

3.2.3 Volume

TELSA contains two methods for associating volume with polygons and various disturbances.

Volume is defined in a table that relates age and volume for one or more volume curves. A second table relates some code from the polygon information and a flag that states whether or not the polygon has been managed with the curve that contains the volume information (Figure 3.3). These tables must be defined in the database at the beginning of the setup phase, and may need to be done only once in a region. Then, during the spatial setup phase, each forest cover polygon will be given a code to link it into the table that refers to the volume curve. The advantage of this approach is that, in BC, the volumes predicted from TELSAs will be most comparable to those predicted by FSSIM. The disadvantage of this approach is that it cannot account for changes in yield associated with changing vegetation types, especially those caused by natural disturbances.

An alternative method is to define volume curves by state class. In this case users can enter volume curves for each projectable state class. At least two age vs. volume points must be entered. The model will interpolate between points.

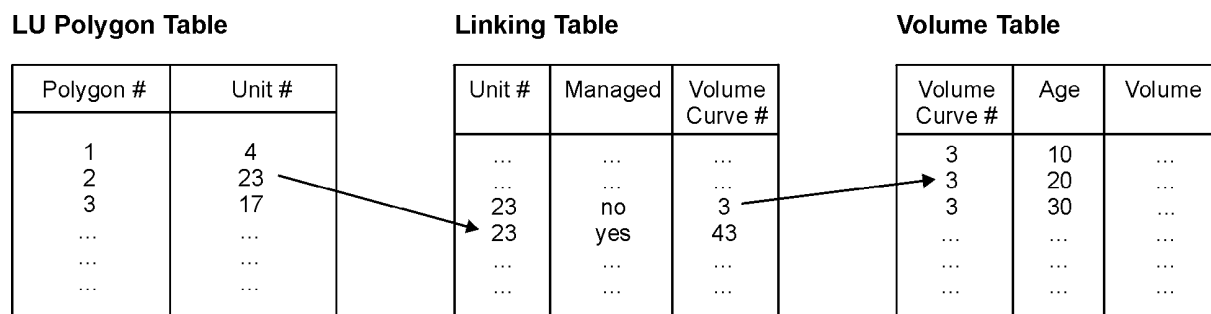


Figure 3.3: The relationship between the three tables containing polygon and volume information.

3.2.4 Effects

In TELSAs, “effects” are defined as changes in polygon attributes not directly related to changes defined by the pathway diagrams (Section 3.3.2). Two types of effects are modelled in TELSAs: effects on age and effects on volume. These are defined as disturbance-based multipliers that are applied at the time of the disturbance (note that both natural disturbances and management activities are disturbances). For example, a thinning may have the effect of reducing age by 30% (i.e., multiply the current age by 0.7), while root disease may reduce the volume by 5% (i.e., multiply the current volume by 0.95).

Currently, if volume is part of the simulation, the volume effects will override any changes in age because age is always calculated from the current volume after the volume has changed. For example, suppose a polygon is 100 years old, has a volume of 100m², and a linear volume curve. Also suppose that after the disturbance the volume is changed by 25%. The new volume would be 75m². The model then looks up this volume in the volume table and determines the closest related age, in this case age 75, and assigns it to the polygon.

Note that the Age attribute of polygons is independent of the state transition diagram. A separate attribute called state based age is derived from the state transition diagrams described below. For example if a pathway takes a polygon from class A (Ages 100 – 150) to class B – (Age 125 – 140) the new state based age would be 125 – independent of any volume changes associated with the ‘effects’ described above.

3.3 Vegetation setup

All of the information about vegetation and its dynamics usually needs to be setup only once per landscape.

3.3.1 Vegetation dynamics rules

Vegetation dynamics, the changes in composition and structure of the vegetation, are determined by three main factors: succession, natural disturbances, and management actions. To assess changes at the landscape level and over long time periods, it is important to properly account for the combined impacts of all three factors.

The approach selected for TELSAs is based on general concepts of forest succession that have previously been employed successfully in projects with the USDA Forest Service (Kurz et al. 1994, Beukema, Kurz and Pinkham 2002).

Four major steps are required to define the rules that describe vegetation dynamics.

1. Define the stratification of the vegetation in the landscape (PVT or BEC variant).
2. For each stratum, define the successional pathways in the absence of disturbance.
3. Define the natural disturbances, their probabilities, and their impacts on succession.
4. Define the management actions and their impacts on succession.

Each of these steps is described in more detail below. These steps can all be done in VDDT; they result in parameter sets that can be imported in the database manually and utilised by TELSAs to simulate the changes in vegetation composition and structure.

We emphasise the strategic objectives of the model. At this time, the rules that describe vegetation dynamics are for different site associations at the BEC variant level only and do not capture further differences due to slope, elevation or aspect.

Successional pathway diagrams

Different Successional Pathway Diagrams (SPD) are typically defined for unique ecosystem types in the landscape. For example, in British Columbia, SPDs are often defined at the BEC variants level. The SPDs are made up of a series of “state-classes” that are defined as a combination of dominant cover type and stand structure (structural stage, Appendix 2). The diagrams then describe the possible transitions between these classes under succession, natural disturbances, and management activities (Figure 3.4). Because it must be possible to map the forest cover polygons onto the different classes, each of the successional classes must be defined such that they can be distinguished from the information in the forest cover maps. Note that the cover types, structural stages, and classes defined in the SPD must be imported into the database before any of the pathway information is entered.

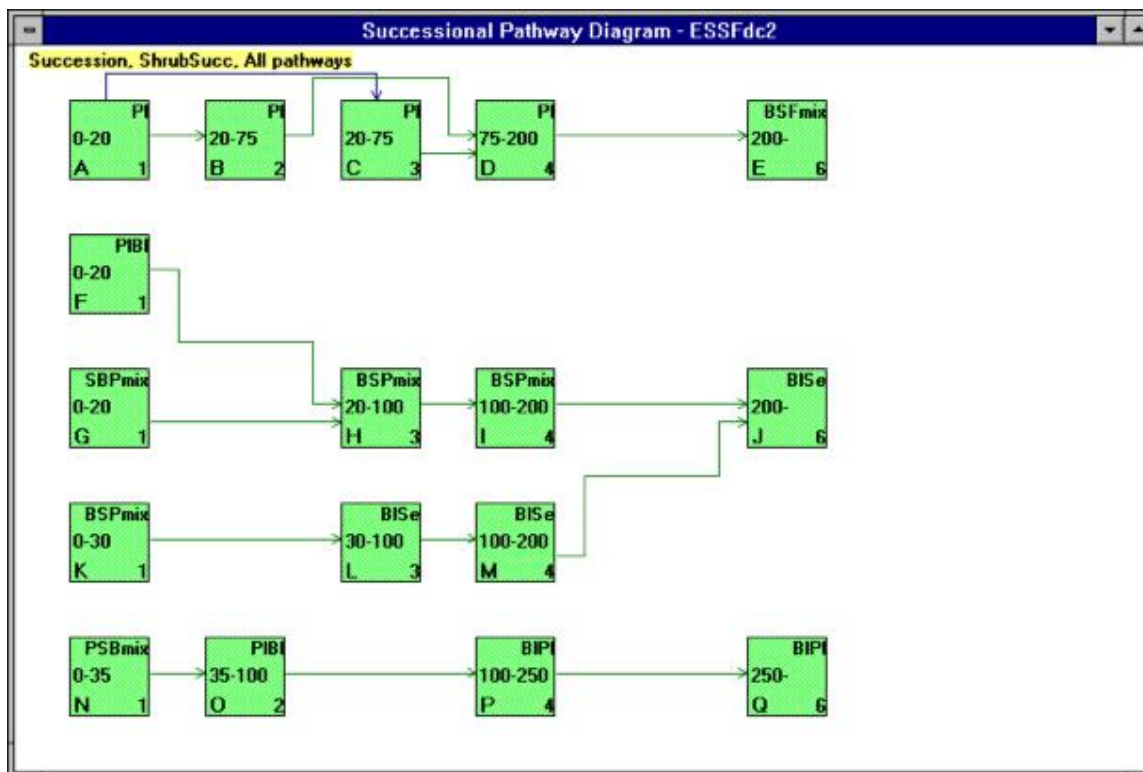


Figure 3.4: Example of a successional pathway diagram. Each box represents a state class defined by a unique combination of dominant overstorey species composition and structural stage. Arrows define succession in the absence of disturbances and the effects of natural disturbances and management actions. The top row in each box defines the vegetation type, the middle row defines the transition time in each class, and the number in the lower right corner defines the structural stage (see Appendix 2).

Deterministic pathways

The first step in creating a successional pathway diagram is to determine the state classes that are encountered in the absence of any disturbances and what other classes may be present purely due to the presence of disturbances. These classes are then connected to describe the transition from one class to the next due to the passage of time. Both the direction of succession and the time for transition from one class to the next are defined.

Natural disturbances

Natural disturbances defined as those that are not direct human manipulations of the landscape (e.g., insects, fire, and diseases), influence forest succession. While it is generally not possible to predict the exact year and location of wildfires or insect outbreaks, vegetation characteristics do affect the probabilities of occurrence of natural disturbances. Successional pathway diagrams define, for each successional class, the probability of occurrence and the impact of major disturbance types. The impact is defined as transition from one successional class to another, or for some disturbances, as altering the successional age within a class. For example, repeated underburns may prevent the establishment of a Douglas-fir understorey in an old ponderosa pine stand. Examples of types of disturbances that can be included in the model are stand replacing fire, underburns, root disease, spruce budworm, mountain pine beetle, and flooding. Each of these must also be defined in the database.

Management

For a management action to have any impact on vegetation dynamics, a pathway describing the impact must be defined. Typically, only those management actions that affect stand structure and composition on the scale of the polygons used in the model are defined. Examples of management actions that can be included in the model are prescribed burning, planting, site preparation, clear cut, partial cuts, and salvage. Each of these activities must also be defined in the database.

Unlike the natural disturbances, management pathways do not include a probability because the TELSAs model uses a different approach to simulating management. Thus, only the impact of the activity on vegetation is defined. However, users may wish to simulate management stochastically as a disturbance.

3.3.2 Landscape definitions

The database contains a number of tables which give the model information about the vegetation and vegetation classification systems used in the model and in the landscape. Each of these tables must be initialised at the beginning of a run with a new landscape. In many cases, if several landscapes are being done in a similar region, the definitions that are setup for one landscape will be sufficient for all landscapes.

The various polygons in the landscape will be described by **state classes**. These are unique combinations of **cover types** and **structural stages**. All occurrences of each of these (i.e., all cover types that appear, all structural stages that occur, and all classes that occur) must be listed in tables in the database before the vegetation dynamics rules (Section 3.3.2) can be imported into the database. Cover types can be grouped in various ways, for management, spatial analysis, mapping, or graphing, and each of these groupings must be described in the database.

The landscape can also be stratified into ecological regions, such as **BEC variants or PVTs**. These BEC variants can be grouped into **BEC zones**, and **NDTs** (“Natural Disturbance Type” groupings defined by the Biodiversity Guidebook). BEC zone, NDT, and age can be combined in various ways to create **seral stages**. Each of the items in bold, and their relationships, must be defined in the database. Note that users in regions that do not use BEC variant as the ecological stratification must still define the information in these tables, as appropriate to their area.

3.3.3 Landscape cover translation

Each of the forest cover polygons in a landscape contains information about its BEC variant, the species present in the polygon and the age of the polygon. This information must be translated into the corresponding successional pathway diagram and class defined above. A translator program uses a series of rules to map the forest cover polygons onto a state class. The resulting information is then imported into the main TELSAs database.

The translator program, called State Class Assignment Tool (SCAT), operates in a separate database using information from VDDT, the forest cover map, and the main TELSAs database. It assumes that the forest cover map has already been added to the TELSAs database. When using the tool, users must first define a number of rules:

- how to assign combinations of species, their percentage contribution to overstorey, and ages, to their resulting class (Table 3.3);

- how to treat any discrepancies or synonymous terms (i.e., in the forest cover database western hemlock may be coded as either ‘H’ or ‘HW’); and
- how to determine whether a record should be in a different ecological region (e.g., if western cedar is present, and the polygon thinks it is in the BEC variant ESSFwc2, change it to the BEC variant ICHmw3). This rule is optional.

Secondly, the model examines the database and applies the rules. It lists each record, the assigned class, and any error or message codes. This becomes an iterative process whereby the user gradually refines the rule until most errors have been removed. At this point, the tool will add the new class information to the main TELSAs database.

Table 3.3: Example of some of the rules used to assign a class from the species and age of a record.

BEC	Species 1			Species 2			Species 3			Age		Class
	Cover	Min%	Max%	Cover	Min%	Max%	Cover	Min%	Max%	Min	Max	
MSdm2	Se	30	80	PI	10	50	BI	10	50	0	20	SBP1
IDFmw2	Fd	30	80	Ep	10	50	Cw	10	40	0	20	FdCw1
IDFmw2	Fd	30	80	PI	10	50	Ep	10	40	0	20	FdEp1
IDFdk2	PI	30	80	Sx	10	50	Fd	10	40	0	20	PISx1

The main purpose of the SCAT is to help users assign classes to the records in the forest cover map, and to put the appropriate values into the TELSAs database. It is also possible to do this step manually directly in the database, an option that may be preferred if the assignment rules are relatively straightforward or if there are a few remaining polygons that cannot be classified by the refined rules.

4.0 Scenario and Run Definition

The activities described in Section 3 will result in several parameter sets that describe the dynamics of the vegetation in the landscape, the roles of natural disturbances, and the management options and their impact on succession. In general users can then choose from the pre-existing parameters sets to define a scenario and a sequence of runs.

4.1 Defining a scenario

At the top level, a scenario can be defined by selecting from a number of existing parameter sets. Each table of parameter values in the database can be identified as part of a set, and some sets are made up of other subsets. Users select from a number of different existing parameter sets to create or edit the scenario. Some of the general parameter sets and flags that can be selected are:

- management:
 - activity limits;
 - salvage criteria;
 - AHA cutting rules;
 - activity constraints;
 - management Systems;
 - activity sorting
 - randomization of operational unit priority
 - randomization of management system sequences
- vegetation transition rules (management, disturbance, and succession rules);
- natural disturbance parameters (size class distributions, trend multipliers, and temporal pattern);
- effect rules (age effects and volume effects);
- spatial information (planning zone and operational unit for each minimum polygon);
- flags:
 - do management (if this is turned off, no management parameter sets need to be selected);
 - do green-up (if management is turned off, green-up will be turned off as well); and
 - do natural disturbances (if this is turned off, salvage will not happen either).

In all cases, defining a scenario consists of choosing from sets of parameters that have already been defined. Defining new parameter sets must be done before a scenario is created.

4.2 Scenario execution

Upon completion of the definition of the scenarios, the user must make a few final decisions prior to executing the model simulation. These include:

- selecting the number of years for which to run the simulation;

- selecting the number of times the simulation is to be executed (useful if there are some parameters, such as natural disturbances, or management that include stochastic variation);
- selecting the frequency with which to save the state of the landscape during the simulation;
- a flag for whether the natural disturbances in each Monte Carlo simulation should start in a different place in the sequence of multipliers; and
- selecting the age classes to use for landscape output.

This information is combined into a “run.” The interface allows users to see which runs have been defined in the database, and shows the runs for which output is currently present in the database. Users can create new runs or, after deleting output, re-run an existing run.

Users interact with the main TELSAs model using the batch controls form in the database editor. When the main model runs, it reads the batch controls table and simulates the appropriate run, placing the output information about disturbances and the state of the landscape into the database. A status window is visible during the simulation to show the run and Monte Carlo that are being simulated, and the number of time steps that have been completed.

5.0 Model Algorithms

TELSA loops over each scenario, each Monte-Carlo run and each time-step during a simulation. TELSAs operates on all projectable polygons in the landscape, simulating both spatially independent processes such as succession and processes dependent on spatial context, such as management or natural disturbances. Non-projectable polygons such as lakes and glaciers are ignored.

5.1 Succession

Succession is the first process simulated each time step in TELSAs. For each minimum polygon, the model looks at the current class of the polygon, the length of time the polygon has been in the class, the length of time polygons should stay in the class, and the defined succession pathway from the class (see Section 3.3). If the polygon has been in the class for the required number of years, it will be moved to the class indicated by the succession pathway. In all cases, the age of the polygon will be increased.

5.2.a Natural disturbances

Natural disturbances are stochastic events that change the rate of succession, or the successional class of a polygon. Natural disturbances include insects, pathogens, fire, windthrow, flooding, animal browsing and other events for which impacts should be considered in the analysis.

The simulation of natural disturbances in TELSAs allows for feedback between the condition of the landscape and the amount and type of disturbances that are operating. For example, consider a landscape that was historically dominated by stand-replacing fires in which active fire suppression is exercised. Over time, the age-class structure of the landscape will shift towards older stand ages. If these older stand types are more susceptible to insects, the area annually disturbed by insects will increase as more susceptible stands are in the landscape. TELSAs was designed to simulate the impacts of changes in vegetation characteristics on disturbance types and disturbance frequency.

TELSAs recognises user-defined disturbance types, which are combined into disturbance groups. For example, the disturbance group “Fire” could contain several types of fires (representing different intensities from under-burns to stand replacing). A single disturbance event may consist of various disturbance types belonging to the same disturbance group. For example in a single fire event some polygons may experience stand-replacing fire while others may experience only an under-story burn.

All natural disturbances are simulated with the same set of algorithms, using different parameter values (but see section 5.2.b for the special case of “contagious” disturbance types). The model requires three sets of input information to represent disturbances:

1. For each successional class and disturbance type, the **average annual probability** of disturbance is defined, e.g., a successional class in a BEC variant with a 200-year fire return interval would have a disturbance probability of 0.005. These were defined in the VDDT successional pathway diagrams (see Section 3.3.1).
2. For each successional class and disturbance type, the **impact of the disturbance** is defined in the successional pathway diagrams developed with VDDT (see Section 3.3.1). For example, a stand-replacing disturbance in class X (e.g., a mature Douglas-fir stand) will move the polygon to class Y (e.g., an herb-shrub complex).

3. For each disturbance group, the **size-class distribution** of disturbances is defined. It defines which proportions of the disturbance events are in the six different size classes (see Section 3.2.2).

Optional parameter inputs for natural disturbance groups include:

1. **Between-year variability** or **temporal variation** multiplier sequences. This accounts for the effects of weather and other sources of between year variation that are not related to the condition of the landscape (see Section 3.2.2). Multipliers can be greater than 1 to create higher than expected disturbance levels, less than 1 to create lower than expected disturbance levels, or equal to 1 to leave the expected disturbance level unchanged. Different multiplier sequences can be defined for different Monte Carlo simulations in the same run.
2. **Long-term trend** multiplier sequences. This accounts for the effects of changing climatic conditions or changes in suppression efforts (see Section 3.2.2). For example, a scenario could include the assumption that over the next 100 years the average annual area burned increases by 50%. Different long-term trends can be defined for different planning zones in the landscape.
3. **Minimum and maximum disturbance sizes** for each disturbance group.
4. **Slope multipliers** to take into account the effect of topography on disturbance spread. For example – these multipliers may be used to simulate fires that are more likely to spread uphill than down.
5. **Wind roses** and **wind multipliers** to take into account the effect of wind direction on disturbance spread. For example – these multipliers may be used to simulate fires that are more likely to spread downwind.
6. **Contagious spread (Section 5.2.b)**. Certain disturbance groups such as invasive species or diseases may be simulated using annual spread distance distributions rather than probabilities.
7. **Spatial autocorrelation of disturbance impacts** is optionally defined using a spatial weighting factor from 0 to 1. With a spatial weighting factor value of zero the state transition a disturbance spreading from one polygon to another polygon in the same state will be determined randomly based on the relative probabilities of all the transitions for that state and disturbance group. With a spatial weighting factor value of 1 zero the state transition a disturbance spreading from one polygon to another polygon in the same state will be the same transition as in the source polygon.

TELSA represents all natural disturbances by simulating their impacts on minimum polygons. The same basic approach is followed for each disturbance group. Thus, differences between disturbance groups are due to the landscape characteristics and the parameter sets defined above. For the steps described below, the model loops over disturbance groups and types in the order that they are found in the natural disturbance group table in the database. This order depends on the VDDT files that are imported into the database during the initialisation stage. Usually insects are simulated first then disease, fire, extreme weather and mammals.

1. Calculate the expected area to be disturbed in this time step by multiplying the area of each polygon times the probability of disturbance by each of the disturbances in the defined disturbance group in that class and by the appropriate trend multiplier (based on planning zones). The probabilities of disturbance have been assigned to each successional class during the set-up phase. This disturbed area in each class must be summed for each disturbance group in each BEC variant.

2. At the same time, all minimum polygons that contain a non-zero probability pathway for any of the disturbance types within the disturbance group are added to a list of eligible polygons for this disturbance group and the maximum product of probability by polygon area is stored in memory.
3. Modify the area estimate (from 1) based on the defined temporal variation multiplier.
4. Determine the number of disturbance events in each size class that will occur during this time step. To do this, the model creates a cumulative distribution based on the user-defined size class distribution and randomly draws incidences from this distribution until the total area (from 3) is allocated.
5. Pick a target size class from the size class distribution (from 4). Start with the largest size class that has at least one incident possible. Select an area at random from within that size class. For example, if the size class 1,000-10,000 ha is the target size class, the target disturbance size may be 3,521 ha.
6. Choose an initiation polygon to start the disturbance. Polygons are selected randomly from a list and then the product of their probability of disturbance by their area is compared to the maximum product of area by disturbance probability of any polygon on the landscape (from 2). Multiply the area weighted relative probability by any initiation multipliers from an initiation multiplier map. If a random draw is lower than the target polygon's corrected probability relative to the maximum the disturbance will start at that polygon. This step is repeated until the disturbance starts.
8. Before starting a disturbance check if this disturbance group has user defined constraints either on size limits or incidents per size class. If such constraints exist, check that the disturbance can be large enough. If not, the disturbance will not occur and another initiation polygon must be chosen (step 6). For this reason, user imposed size class and size limits will tend to increase model run time.
9. Spread the disturbance from the source polygon to the eligible adjacent minimum polygon(s). Each time the disturbance is about to spread determine the spread probability using the following steps:
 - a. Determine the relative disturbance probability of the target polygon compared to all other neighbours of the source polygon.
 - b. Determine the slope between the source and target polygons and multiply the relative probability from "a" by the slope multiplier for this slope.
 - c. Randomly draw a wind direction from the wind rose for this part of the landscape, determine the difference between spread direction and wind direction, and multiply the wind multiplier for this difference by the slope and condition multiplier from "b".
 - d. Draw a random number between 0 and 1. If this is less than the condition by slope by wind multiplier from "c" then the disturbance spreads to the target polygon.
9. When all immediately adjacent eligible polygons have been targeted, spread the disturbance to those that are in the next "ring" (i.e., adjacent to the polygons that have just been disturbed). Use the rules from step 9. Adjacent polygons may be in any BEC variant, but must be on the list of eligible polygons.
10. Once the disturbance spreads to or starts in a polygon determine which disturbance type within the disturbance group will occur. If the target polygon has an immediate neighbour that has: a) already been disturbed by this event, and b) the same pre-disturbance state class as the eligible adjacent polygon, then adjust the post-disturbance transition pathway probabilities for the eligible adjacent simulation polygon as outlined below:

$$PW_{s,i} = SWF_a + (1 - SWF_a) * \frac{P_{s,i}}{\sum_j P_{s,j}} \quad \text{for } i = t$$

$$PW_{s,i} = (1 - SWF_a) * \frac{P_{s,i}}{\sum_j P_{s,j}} \quad \text{for } i \neq t$$

Where

t = post-disturbance state class for the immediate neighbour of the eligible adjacent simulation polygon that has a) already been disturbed by this event, and b) the same pre-disturbance state class as the eligible adjacent polygon

$PW_{s,i}$ = weighted probability of transition from source polygon pre-disturbance state class s to post-disturbance state class i

SWF_a = spatial weighting factor for disturbance group a

$PW_{s,i}$ = weighted probability of transition from source polygon pre-disturbance state class s to non- post-disturbance state class i

$P_{s,i}$ = original (non-weighted) probability of transition from source polygon pre-disturbance state class s to post-disturbance state class i

If both condition a and b (from above) are not met then this decision on the post disturbance state transition is based on a random draw and on the relative probabilities of the individual disturbance types. For example if a fire spreads to a polygon that has a 0.01 probability of a stand replacing fire and a 0.005 probability of an under-burn, two times out of three the fire will spread as stand replacing.

11. Stop spreading the disturbance when either:

- there are no more adjacent eligible areas to spread to; or
- the appropriate target disturbance size (from 5) is reached for that incident.

In either case, the incident is recorded in the appropriate size class. Thus, if the target size class is 1,000–10,000 ha and the actual disturbance size is only 678 ha, the incident will be recorded in the size class 100–1,000 ha.

12. Repeat steps 5 to 11 until the target area disturbed has been reached for that BEC variant and disturbance group.

13. Repeat steps 4 to 12 for each BEC variant and disturbance group.

The effect of each disturbance on a minimum polygon is based on the pathways that are defined for the disturbance and on the disturbance-specific effect parameters in the database. The pathways determine the polygon's new state, whether the age was reset, and whether the succession rate was affected by the disturbance. The pathways also determine the adjustment to the number of steps spent in the class (whether it is the same as the pre disturbance class or not). The effect parameters may then change the age of the polygon and, if volume is being used, the volume of the polygon.

In each time step, a polygon may only be disturbed once by each disturbance group. Multiple disturbance groups can disturb individual polygons provided that prior disturbances have put them in a state that is eligible for the subsequent disturbance. For example, a polygon may only be disturbed by one bark beetle outbreak per time step, but after such an outbreak a fire may burn the polygon in that same time step.

5.2.b Contagious natural disturbances

Contagious natural disturbance groups such as invasive weeds or diseases are simulated differently from the "regular" natural disturbances described above. To simulate contagious natural disturbance groups users must define the following parameters for each group:

1. source polygons for contagion at the beginning of the simulation;
2. a spread distance distribution (m/year) for spread into the most vulnerable vegetation state. There are currently three options — Pareto, negative exponential and log-normal;
3. the contagious period (years) after initial infection; and
4. a list of other disturbance types, natural or managed, that can deactivate the contagion.

Each time step for each contagious disturbance group the model will loop over all the polygons that are currently infected. If the life span of the infection has passed the model will remove that polygon from the list of contagious polygons otherwise the model will attempt to spread the contagious disturbance to neighbours. For each neighbour the model will determine the centroid to centroid distance from the source polygon. For each year that the source polygon has been contagious the model will draw a distance from the annual spread distance distribution. This spread distance is multiplied by the following number:

$$\left(\frac{V}{V_{MAX}} \right)^{CS}$$

Where:

V is the vulnerability of the target polygon to invasion (defined in the transition pathway)

V_{max} is the maximum vulnerability to invasion

CS (≥ 0) is the condition sensitivity of the invasive agent.

As with natural disturbance spread multipliers (5.2.a), the spread distance is multiplied by user-defined slope or wind multipliers. If the spread distance exceeds the centroid to centroid distance then the target polygon will be disturbed and added to the list of contagious polygons.

5.3 Salvage

The simulation of salvage on disturbed polygons occurs immediately after all natural disturbances, if management is being simulated. Disturbance incidents above some minimum size, as defined by the user, are potentially eligible for salvage. The model examines each minimum polygon that was part of the disturbance incident to determine if it meets the user-defined salvage criteria. These criteria are, for each eligible disturbance type, planning zone and cover type:

- the minimum age of the polygon before it was disturbed; and
- the maximum number of years that have elapsed between the disturbance and the salvage activity.

Finally, for the minimum polygon to be salvaged, the successional pathway associated with salvage (which defines what happens to the successional class of the polygon as a result of the salvage) must be present in the database. As with disturbances, the effect of the salvage on a minimum polygon is based on the pathways that are defined for the disturbance and on the disturbance-specific effect parameters in the database. Due to the above constraints, not all polygons within a disturbance incident may be part of the corresponding salvage incident. Thus two polygons that are part of the same salvage incident are not necessarily adjacent.

A maximum amount of area (or volume) can be salvaged in a single year, as defined in the database. Other constraints on management activities (see below) are not applicable to salvage.

Areas salvaged will affect the amount of area or volume that can be managed in the standard management section of the model. In the model, salvaged areas are applied towards the activity limit for different management activities, depending on user defined criteria for each planning zone. Thus, in years with high salvage activity other management activities may be reduced.

5.4 Aggregated harvest areas

Aggregated harvest areas (AHAs) are pre-defined areas that can all be harvested in a single pass in order to make a large patch or to “clean-up” an area that is highly fragmented. This is an optional part of any simulation. When it is present, it operates after natural disturbances and salvage, but before standard management is applied.

In order to simulate AHA cutting, users must have created a map layer that can be used to define the patches that may be cut, as well as a number of other parameters:

- the minimum percent of area that should be in the youngest and two oldest seral stages;
- the minimum and maximum ages for the patches;
- the activity pathway to use for each BEC variant;
- the map layer to use (either a planning zone layer or the operational unit map);
- the criterion for picking between the eligible AHAs:
 - the largest percent of area in patches greater than some given size;
 - the largest percent of area in patches less than some given size; or
 - randomly picked; and

the number of years before starting the first AHA cut, between attempted AHA cuts, and before areas in the AHA can be managed again (by either AHA cutting or standard management). This will also restrict

any other activity, including planting, fertilising, etc. If users want these activities to be conducted regardless, they should implicitly include them in the successional pathway.

In years in which AHA cutting can be attempted (as defined in the last item above) TELSAsimulates AHA cutting using the following steps:

1. For each defined AHA, (either a planning zone or operational unit), that is potentially eligible to be cut, determine the percent of the AHA that is in seral stage 1, the youngest, and in seral stages 3 and 4, the oldest two stages.
2. Determine those AHAs from Step 1 that have more than the minimum percent of area in the youngest seral stage and in the oldest two seral stages. If the user wishes to pick an AHA from this list to harvest at random, proceed to Step 5.
3. Determine the patchiness of each AHA from Step 2 by determining the amount of area that is in patches formed by adjacent minimum polygons within a user-specified age range.
4. Pick the AHA that contains either the largest percent of area in big patches (i.e., the area in which the harvesting will create the largest patches), or the largest percent of area in small patches (i.e., the area that is currently the most fragmented, and thus may be the one to benefit the most from cutting).
5. Start harvesting the eligible minimum polygons within the selected AHA. Eligibility of the polygon is based on the existence of the appropriate pathway for the polygon's successional class. AHA activities are subject to the age constraints defined under activity constraints but not to the block size or greenup constraints. Stop harvesting when either all eligible polygons have been harvested or the activity limit for the particular activity type has been reached. Note that if the activity limit was reached before the AHA was fully harvested, the AHA cutting will continue in the next year of the simulation, skipping Steps 1–4.

The activity type that identifies the pathway for the AHA cutting can be one that is specific to AHA cutting or the same as one that is used in a management system for standard management. If the activity is one that is used also for standard management, the cutting that occurs will contribute to the limits, and the amount of standard management in that year will be decreased. If the activity is one specific to AHA cutting and does not occur in any applied management system, the standard management and the AHA cutting will remain totally independent. In the most extreme case, both cutting types could operate at their limit in the same year.

5.5 Other management activities

After the model has simulated succession, natural disturbances, salvage and aggregated harvesting on the landscape, other management activities are applied. Management activities are simulated by creating management units (treatment blocks); reviewing, for each activity, the eligible polygons (based on the management system and other constraints); and by implementing the activity for each management unit until either all eligible polygons have been treated or the upper area limit of the activity has been met, whichever occurs first. Management units are ordered by operational unit and then prioritised.

Management activities are simulated using the following steps:

1. During year 0 the model creates management units from polygons that have a harvesting history prior to the simulation. This allows for the completion of an activity set for the given polygon. For example, if a polygon has been recently harvested, it will be assigned to a management system according to BEC/Planning Zone rules defined by the user. If that management system

involves planting and the polygon is within the planting age range, it can then be planted. If a polygon with a management history prior to the simulation is older than its release age it will not be included in a management unit. Note that management units defined as previously harvested in the landscape cover map and therefore created in year 0 may fall outside the acceptable age range defined in the system constraints.

2. In all other years, at the beginning of the management section of a time-step, the model loops over all existing management units to check two things.
 - a) Has any part of the management unit has been disturbed by a stand-replacing disturbance? If so, then those polygons that were disturbed are removed from the management unit, but the management unit remains intact.
 - b) Is it time to dissolve (release) the management unit? If so the minimum polygons will no longer be part of that management unit.
3. Select an operational unit. In the first year, the first operational unit potentially managed will be the one with the highest user-defined priority. In following years, the first operational unit that is potentially managed will be the last operational unit that contained any management in the preceding year. The sequence of priority in management for each operational unit is set by the user or can be randomized by the model for each Monte Carlo simulation.
4. Create new management units.

For each combination of planning zone(s) and ecological stratification (e.g., BEC Variant), the user will have defined one or more management systems, the proportion of each system within that area, and the degree of spatial aggregation of the systems. These management systems contain information about the acceptable age range for polygons within the management unit, and the target size range of the units (see Section 3.2.1).

Before actually creating a management unit, the tool picks the management system for the new unit so as to use some of the management system information when creating the management unit. The spatial aggregation defined by the user specifies how aggregated to make the management systems in the specified planning zone and BEC variant. For example, if a planning zone and BEC variant combination were to have two management systems assigned, in the aggregated case, the management systems would be assigned to adjacent polygons, while in a random case, they will be more spread out (Figure 5.1). The tool does this by picking a random number between 0 and 1 and comparing it to the aggregation index, which is also a number between 0 and 1 where 1 is highly aggregated and 0 is random. If the random number is less than the aggregation index, then the model will use the last used management system. If the random number is higher, this is the first management system assigned in the particular planning zone and BEC variant combination, or all applicable area has been assigned to the previously used management system, the tool picks a management system at random from the existing possibilities.

Once the management system has been selected, the management unit can be built. Management units are created by starting with a minimum polygon and then adding on additional similar polygons until the resulting management unit is within the target size range. "Similar polygons" are defined as those polygons that are within a given age range of the starting polygon, have the same cover type group, and are located in the same operational unit, planning zone(s), and ecological stratum. Once a management unit is within the target size range, the model uses a random number to decide, based on the current size of the unit and the range of sizes that are possible, whether or not to try to add another polygon. The equation used to calculate this is:

$$x \leq \frac{Area - Size_{\min}}{Size_{\max} - Size_{\min}}$$

where x is the random number used to make the decision, $Area$ is the current area of the management unit, and $Size_{\min}$ and $Size_{\max}$ are the minimum and maximum sizes that are allowed for the management unit. If the equation is false, the model will attempt to increase the size of the management unit, while if it is true, the management unit is considered complete.

In order to maintain a uniform size distribution of management units, the model splits the possible range of sizes for each management system into bins. The number of bins used is between 1 and 10 depending on the ratio of average polygon size to the size range allowed for the management system. The model uses the maximum number of bins that will maintain a ratio of 10:1 for bin range to average polygon size. Each time a new management unit is being built, the target size range will be the bin that is least represented by existing management units. If two or more bins are equally underrepresented, the largest one is chosen.

When the unit is made, the tool picks the next closest polygon that is not already part of a management unit, assigns it to a management system, and begins to create the next management unit. The selection of the management system will be influenced by the aggregation factor described above. Once all units have been created, the tool makes a final pass over all unassigned polygons and attempts to add them to existing management units (even if the management unit would then be bigger than desired). If that is not possible, and a management unit could be created that is 2 ha or larger, the polygons will become a new management unit. Some polygons may still be left unassigned as unmanaged “slivers” in the landscape. This is especially likely if there are long thin polygons of a different planning zone than the surrounding area (e.g., riparian management zones, which may cross several ecological boundaries).

Unprojectable polygons will not be added to any management unit. Other areas may be designated as unmanaged (e.g., parks) and will also not be assigned to a management unit. These areas may still be eligible for natural disturbances.

The number of minimum polygons that make up a management unit is highly variable and depends on the target size range of the management unit, the size of the minimum polygons, and the spatial arrangement of the minimum polygons. Management units will tend to be smaller in areas that are highly fragmented or that contain large numbers of planning zones or ecological units.

The model uses the following constraints when building management units:

- a) The model only builds management units within the operational unit that is being managed. Thus, management units will not be built across the entire landscape if activity limits are met earlier.
- b) The polygons eligible for becoming part of a management unit are restricted to those that are:
 - of harvestable age;
 - not currently assigned to a management unit;
 - in a state class that can be managed; and
 - not affected by green-up constraints.

These constraints are to ensure that every polygon that is added to a management unit, and therefore every management unit, is potentially harvestable at the time it is created. No other polygons will be eligible to be added to a management unit at this time.

- c) If the management unit would be less than 10m², it will not be created.

- d) Management units that are less than the minimum desired size (as set by the user as part of the management system or activity constraints) will only be created in operational units for which bigger management units were created in the current year.

The last two constraints (c and d) help to manage issues related to tiny management units. When building management units, there are often a number of polygons that cannot be assigned to a proper management unit because they cannot be joined with enough neighbours to make a management unit that is within the specified size range. They are limited by being an incompatible cover type, age or in a different planning zone, operational unit, or BEC than their neighbours. When tiny management units are created, they can be managed, and can create green-up constraints in the surrounding management units. The last two constraints help to reduce the number of very small management units, and thus reduce their impact on model results.

The management unit building code builds management units and assigns management systems according to rules about aggregation, size ranges, and proportions of management systems in each planning zone / BEC combination. The user defined proportions of management systems assigned to the landscape will only take into account assignments made each year, not existing management units. Therefore, it is possible that the actual proportions of management systems assigned to the landscape will deviate from the user defined proportions. This is particularly likely if competing management systems have strikingly different durations (for example, a recursive partial cut vs. a one time clearcut).

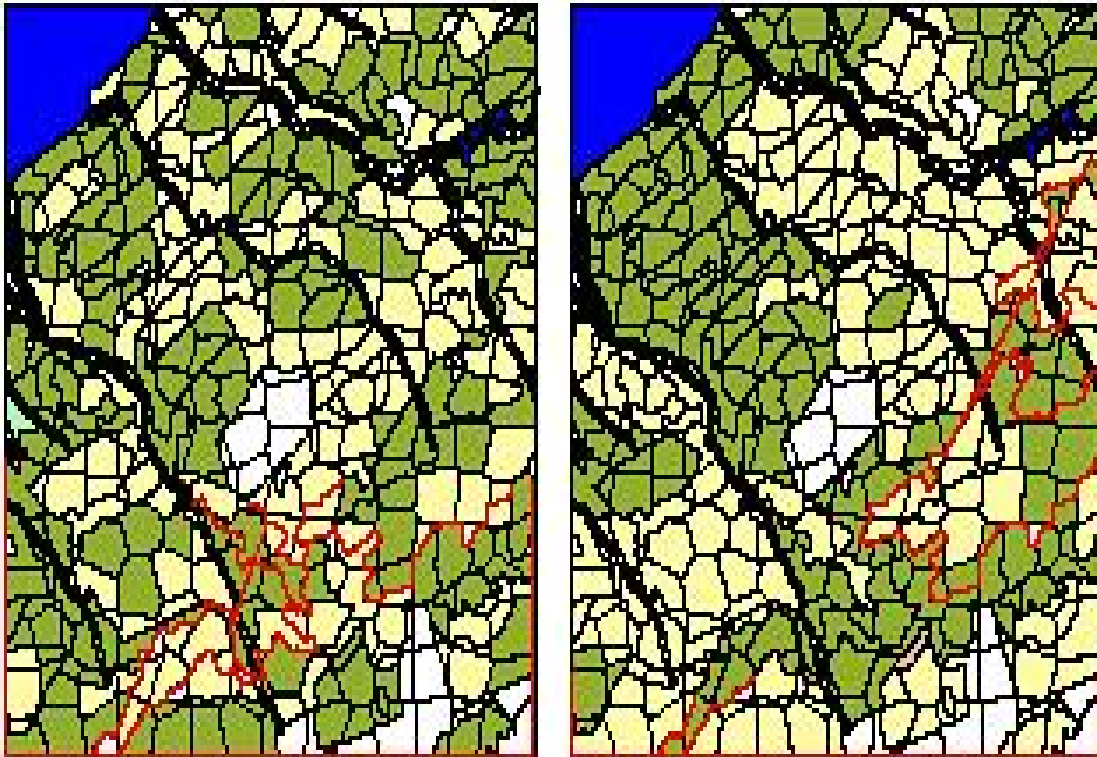


Figure 5.1: Example of a landscape after the management units have been created, using an aggregated or a random spatial assignment of the two management systems. The figure on the left is the random assignment, while the one on the right is the aggregated assignment. Dark areas are clear cuts. Light areas are partial cuts. White areas are non-projectable polygons.

5. Once management units are built the model applies management activities.

a. Setup stage.

Two setup steps occur before management proceeds.

1. Identify all management units that could potentially be affected by a particular management activity, based on the presence of the management activity in the management system assigned to the management unit.
2. Calculate the age of each management unit. Management units may contain multiple minimum polygons, and these polygons may, due to the initial conditions and natural disturbances, have different ages. The age of the management unit is calculated as an area-weighted average of all the minimum polygons contained within the unit. This must be calculated each time step.

b. Determine which activity to simulate.

Within the operational unit, the model loops over the possible management systems and activity types within the management system.

c. Determine which management units are eligible for the activity.

Eligibility is determined from several sources.

1. The management unit must be a member of the current management system that is being examined.
2. Each management unit must meet the age criteria of both the management system and any additional planning zone or BEC variant constraints for the activity.
3. If green-up constraints are being used, the ages of the neighbouring management units must be checked to ensure that they are greater than the minimum age defined by the constraints.
4. The model must check to ensure that either the activity has not yet been done, or that it has been long enough since the activity was done that it is eligible again. At this time, it may also check to ensure that the previous activity in the activity list has been done or is no longer eligible (in cases in which the age range of two or more activities overlaps).

The result of this step is a list of management units that are potentially eligible for treatments. Note that the model assumes that the tool that built the management units made the sizes correctly and so does not check the sizes again. This will allow management units that were intentionally made slightly bigger or smaller than the range to still get managed.

d. Sort the management units by some priority rules.

The list of management units will be sorted according to the user's specification:

1. highest age first;
2. highest volume first; or
3. randomly.

e. Apply the activity to management units.

Activities will be applied to each management unit in sequence, starting from the top of the list. Before each unit is managed, however, the model first checks to see if managing that unit would violate the activity limits or if the management of previous activities has made this management unit ineligible because of green-up constraints. If neither of these rules is violated, the unit will be managed. Due to natural disturbances, however, each minimum polygon must be checked to see if a pathway exists for the management

activity. In some instances, only parts of the management unit will actually be managed, i.e., those minimum polygons in a management unit that meet the eligibility criteria. If management is applied, the effect of the management will be based on the information associated with the pathway, and the activity-specific effect parameters. The effect parameters may change the age of the polygon and, if volume is being used, the volume of the polygon. The age of the management unit will be recalculated after the disturbance is applied (Section 3.2.4).

- f. Repeat steps b to e for each activity, until
 1. all eligible management units have been treated, or
 2. the total limit (area or volume, depending on the user's definition) for this activity has been reached.
6. If a newly created management unit is not managed, dissolve it so that the polygons may be reused or reassigned next year.
7. Repeat steps 3 to 6 for each operational unit. In some cases no activities will be done in an operational unit because the limit for an activity may have been reached in an earlier unit.

5.6 Roading

TELSA optionally maintains an index to the roading density in each minimum polygon in the landscape. Roads are created through any management activity, including salvage. Different road densities are created through different types of activity (Table 5.1). The road density is increased to be at least a given density at the time of the activity and over the next three years; the density is gradually decreased to account for the deactivation of temporary and semi-permanent roads. In all cases, some of the roads are permanent, so all polygons that have been affected by any management activity will have a roading density that is at least the density of the permanent roads (Table 5.1).

In addition to tracking a road density index, TELSA can activate and deactivate roads to individual minimum polygons (optional). To do this users are required to prepare a road map during the map preparation stage of the model initialisation. Users must also define for which management activities roads are built and how long different types of roads remain activated. When road-building activities occur, the model uses the prepared roadmap to create a road from a minimum polygon at the edge of the management unit to the closest user defined exit point from the study area. The road segments used are chosen such that the road is the shortest possible. After the model is run the map output tool can create maps of roads and their status at different time intervals.

Table 5.1: Summary of the road density after different types of cutting. After an activity, the polygon is given the amount of roads in the Total column. The following year, the density is reduced by the amount in the Temporary column, and the following year by the amount in the Semi-permanent column. By the third year after an activity, assuming no other activity has occurred, the roading index will be the amount listed in the Permanent column.

Activities	Road density (km/ha)			
	Total	Temporary	Semi-permanent	Permanent
Clear cuts, planting, site preparation, salvage	1	0.25	0.25	0.5
Partial cuts	4	1	2	1

5.7 Polygon attributes

Users can now optionally track attributes associated to specific polygons. Examples of such attributes may include snags, downed woody debris and fuel. Users initiate the density of the attributes on the landscape on the LU Map. They then define rules about how the attributes change based on polygon aging, state, and disturbance history as well as external factors such as climate. The model tracks these polygon attributes and prints attribute densities per polygon to the database at user selected time intervals.

5.8 Polygon Forcing

Polygon forcing allows users to force the state class of polygons independent of landscape condition. In this way different planning scenarios for features such as pipelines, highways, and even towns can be incorporated into a simulation. If any Polygon forcing information was loaded for the run the model checks each year for polygons to be forced. If LU Polygons are to be forced the model changes the state class of the associated minimum polygons to the state class identified in the user input.

5.9 The Age of a Polygon

For each polygon, two age variables are tracked: absolute age and state based age:

Absolute age is incremented by one each year. It is affected by disturbances and management based on the effects defined by the user for these events, either through volume or age effects and by whether the pathway age reset flag is yes or no. Absolute age is not affected by successional or disturbance pathway variables. Because of this it is possible for the absolute age of a polygon to be outside the range of the age of the class a polygon is in. The absolute age of a polygon is used to determine whether or not that polygon is eligible for management, salvage or AHA's as well as for the volume calculations of a polygon and to determine its seral stage.

State based age is defined as the beginning age of a class + the number of years a polygon has been in a class + any adjustments to the years a polygon has been in a class based on the transition pathways it has experienced. It is not possible for the state based age of a polygon to be outside the range of its class. State based age is used for polygon based attribute calculations and in determining whether a successional and disturbance pathways is possible.

This example illustrates how the two types of ages are tracked. A polygon is in a class ranging from ages 100 – 200. The polygon is aged 110 years old. The polygon is hit by a partial cut which removes 20% of the volume. Based on the new volume the absolute age of the polygon is now calculated from the volume vs. age curve as being 90 years old. Based on the pathway the polygon is still in the same class. The absolute age of the polygon is now outside the range of ages for the class. The transition adjustment to the years in class of the polygon is actually a positive value of ten years – the partial cut reduces competition and increases the rate of succession. The state based age of the polygon is now 120 years.

5.10 Output

The TELS Main Model currently produces five output tables in the database and three to four output ASCII files. The database tables are all accessible through the Graphing Tool and the Map Display Tool. The ASCII files are simply produced for reference purposes and are overwritten with each new simulation. Each of the types of output is described more fully below.

5.10.1 State output

There are two tables created that contain information about the state of the landscape at every reporting time step. Users define the reporting interval when setting up the run (Section 4.2). One table contains detailed information about each projectable polygon in the landscape. This information is used by the Map Display Tool to create maps of age class, seral stage, and cover type; by the Spatial Analysis Tool to create the age and cover type maps that it uses as the basis for the analysis; and by the Graphing Tool to create graphs of cover type distributions:

- run identification: Run number, Monte Carlo number, Year;
- minimum polygon number;
- state class;
- area (m²);
- age (years) calculated from the effects defined by the user of the disturbance history of the polygon;
- road index;
- volume;
- proportion of volume in soft wood; and
- State Based Age – this is the age derived from the successional pathway diagram calculated as the beginning age of the class + the number of years a polygon has been in a class + any age adjustments caused by the disturbance history of the polygon.

The other table summarises the information into a number of categories. This makes the table much smaller and faster to access, which is important for the Graphing Tool. Maps cannot be created from this table.

- run identification: Run number, Monte Carlo number, Year;
- planning zone;
- BEC variant;
- age class;
- seral stage;
- area (m²);
- road index;
- volume; and
- proportion of volume in softwood.

Planning zone information is given for each individual planning zone, as well as the entire landscape as a whole (planning zone id 0). Because planning zones may overlap, the sum of the all area in the individual planning zones may be greater than the area reported as being in the landscape.

5.10.2 Disturbance output

Three output tables are produced with information about disturbances. These are produced in any year in which a disturbance (managed or natural) occurs. The most detailed table is the one containing

information about each minimum polygon that is disturbed or managed. This information is used by the Map Display Tool to create maps of areas disturbed or the probability of disturbance.

- run identification: Run number, Monte Carlo number, Year;
- minimum polygon number;
- disturbance type (activity or natural disturbance);
- area disturbed (m²);
- state class before disturbance;
- age before disturbance (years);
- volume;
- proportion of volume in softwood; and
- State Based Age – this is the age derived from the successional pathway diagram calculated as the beginning age of the class + the number of years a polygon has been in a class + any age adjustments caused by the disturbance history of the polygon.

This table is also produced in summary form, similar to the one produced for the state of the landscape, and is used by the Graphing Tool.

- run identification: Run number, Monte Carlo number, Year;
- planning zone (see the note in Section 5.7.1);
- BEC variant;
- disturbance group (activity or natural disturbance);
- area (m²);
- volume; and
- proportion of volume in softwood.

The final table lists the total area of each natural disturbance incident, in the year of the disturbance. This table is used by the Graphing Tool to produce graphs on the actual size class distribution of the different disturbances, information that is not available through the other disturbance tables.

- run identification: Run number, Monte Carlo number, Year, Incident;
- disturbance group; and
- area (m²).

5.10.3 Road output

There is one table created that contains information about the state of roads in the landscape at every reporting time step. Users define the reporting interval when setting up the run (Section 4.2). This table contains detailed information about each road segment that has been used in the landscape. This information is used by the Map Display Tool to create maps of roads, their activation status and the number of years since they were created; and by the Spatial Analysis Tool to create the road maps that it uses as the basis for the analysis.

- run identification: Run number, Monte Carlo number, Year;

- road segment (most minimum polygons in the landscape have an associated road segment);
- years since last used; and
- status (Active/Inactive).

5.10.4 Attribute output

There are two tables containing attribute information. Attribute Output and Attribute Summary Output. At each reporting interval, the Attribute Output table carries information for each polygon in the landscape with a simulated attribute. For each attribute and polygon with that attribute – the attribute density per ha is carried. A Boolean field “IsValid” states whether the attribute density has reached a value that can not be evaluated by the user defined rules (division by zero). The Attribute Summary Output table carries the average attribute density by planning zone and BEC variant.

5.10.5 ASCII files

Several ASCII files are produced. These were originally created for informational or debugging purposes, but have been retained because they give additional information about the runs.

The file “time.out” contains information on the time at the beginning of loading a scenario, starting a Monte Carlo run, starting each time step, and ending as well as information about the disturbance multiplier “offset.” This information gives users some idea about the length of time needed for different steps and for estimating the length of time required for different runs.

The file “NoPath.out” lists all polygons on which management was attempted but was not successful because the path did not exist. In most cases this will occur because the management unit is to be managed but no pathway exists. This file is especially useful when using new successional pathway diagrams because it allows the user to check that there are no classes that should be getting managed in this file. The file format is space-delimited columns with no text; so, most users will need to look up the meanings of many of the numbers in the corresponding tables in the database.

- run identification: Run number, Monte Carlo number, Year;
- BEC variant number;
- state class number;
- disturbance type number; and
- age (years).

The file “AHAcuts.out” summarises the area harvested as part of aggregated harvest area cutting (see Section 5.4), in the years in which it was attempted. This file contains space-delimited columns with no text. The columns are:

- run identification: Run number, Monte Carlo number, Year;
- AHA number; and
- area cut (m²).

The harvested area is reported in the database as any other management. This file is just printed so that users can confirm that the model is doing AHA cutting in areas and times for which it was scheduled.

The file “ManUnits.out” lists management units created during the simulation. This file contains space-delimited columns with no text. The columns are:

- run ID;
- year;
- Monte Carlo ID;
- management Unit ID;
- scenario Polygon ID; and
- management System ID.

6.0 Analyses

Reports on the current status of resources in the landscape are necessary to document changes over time associated with natural disturbances and management actions. Three post-processing modules allow users to carry out analyses of the landscape patterns that are produced by the model at each time step (or reporting period). Each module produces output in one of three formats:

1. maps of various criteria;
2. graphs of changes in indicators over time or of distributions at any given time; and
3. tables.

Using the modules, users are able to analyse the results at three different levels:

1. one or more variables in a single run;
2. multiple stochastic runs of the same scenario; and
3. multiple scenarios, either for single or multiple stochastic runs.

The modules are accessible via graphical user interfaces that interact directly with the database that contains information on the entire landscape. This gives users maximum flexibility for queries and display of model results.

6.1 Spatial results

Two types of spatial results are generated: spatial statistics and spatial mapping. Both types use ArcView (version 3.1 or later). The spatial statistics make additional use of the Spatial Analyst component of ArcView. Each component is described below.

6.1.1 Spatial statistics

Spatial statistics are calculated using the Spatial Analysis Tool, and can be determined for any reporting time step. The statistics include:

- patch size distributions;
- an analysis of interior conditions in the landscape for one or more seral stages;
- length of edge between different forest types and stand structures; and
- buffer areas around active roads.

Users have the option of saving the map of the patches, the interior habitat and the road buffers generated by this tool. These maps can then be viewed using the Map Display Tool. All other results are also placed directly into the database where they are accessible by the Graphing Tool.

Because of the complexity of the patches that are produced, and some limitations within ArcView for complicated shapes, the Spatial Analysis Tool changes the map from a shape / polygon-based map into a

grid (raster) map. All the calculations are done on the grid map, and then the resulting map is changed back into a shape file. Some loss of resolution occurs with these transfers, but it is minimal (less than 1%) and the time savings (and the fact that it can actually get done) are well worth the loss. Even with this transformation, some of the calculations are fairly time-consuming (i.e., 30min–1.5 hours per spatial analysis), especially in a highly fragmented landscape. Users are provided with the option to setup batch runs of these analyses so that they can be run overnight or without supervision.

Patches

Before doing the patch size analysis, users must define:

- the age class boundaries, optionally by cover type grouping and BEC variant;
- the size class boundaries for reporting the results; and
- a planning zone map to use to further stratify the results (optional).

The tool first classifies the landscape into age classes using the current characteristics of the polygon and the definitions in the database, in the following order:

- Check if a definition exists for the polygon's cover type and BEC variant.
- If not, check if there is a definition for the polygon's BEC variant.
- If not, check if there is a definition for the polygon's cover type group.
- If not, check if there is any definition for the polygon's age.
- If not, the polygon is classed as having no age class.

Adjacent polygons with the same age class are merged together to form a single patch. Thus, patches are bounded by areas of other age classes, unprojectable polygons, and the edge of the map. Once a patch has been created, a portion of the patch will be attributed to the applicable cover type groups, BEC variants, and planning zones. (Figure 6.1; Table 6.1)

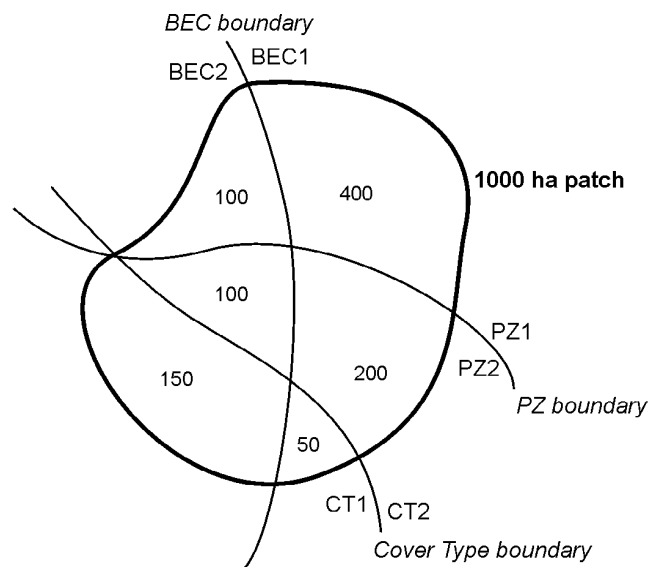


Figure 6.1: Example of the distribution of a patch into cover type groups, BEC variants, and planning zones.

Table 6.1: Table of the count and area of the patch reported from Figure 6.1. Note that in all cases, the patch is still considered to be part of the size class containing a 1000 ha patch.

BEC Variant	Planning zone	Cover type Group	Size class	Count	Area (ha)
1	1	2	500-1500	0.4	400
1	2	2	500-1500	0.2	200
1	2	1	500-1500	0.05	50
2	1	2	500-1500	0.1	100
2	2	2	500-1500	0.1	100
2	2	1	500-1500	0.15	150
Total			500-1500	1	1000

Interior habitat

Interior habitat is defined as the area in a patch (not necessarily the same patch as defined in the patch size analysis) that is more than a given distance from the edge of the patch. Users can define:

- the seral stage boundaries, by BEC variant and cover type group;
- the width of the buffer around the patch; and
- the first and last seral stage to be used (Note that these seral stages do not have to be the same as the seral stages defined in the seral stage table elsewhere in the database).

and, two items that are the same as for the patch size class analysis:

- the size class boundaries for reporting the results; and
- a planning zone map to use to further stratify the results (optional).

In doing the calculations for the interior habitat, it makes patches that are made up of polygons that have the desired seral stages. All applicable seral stages will be combined into a single patch. Patches are created and reported in much the same way as is done for the patch size analysis, using seral stages instead of age classes.

The traditional purpose for this analysis is to determine interior old growth habitat for wildlife purposes.

Border lengths

Users have the option to calculate the length of borders between patches. This calculation uses the patches to determine through the patch size analysis and then reports the length of edge between patches of different age classes or between patches and unclassified areas (such as the edge of the landscape or non-projectable areas).

Road Buffers

If this option is chosen, the tool will calculate the total area of the landscape within a user defined distance from an activated road. The tool will also create a map of the areas within the specified distance. Users can vary the buffer distance for different types of roads. The road buffer area is stratified by BEC variant and Planning Zone (optional).

6.1.2 Spatial mapping

Spatial mapping of model results is achieved through a customised ArcView GIS application. This application connects directly with the Access relational database to determine what results are available for display, obtain the required data, and locate the landscape shape file(s). To map model results, users need only click on the “spectacles” icon in the interface and then answer a series of four to six questions to specify which results they wish to view. The application provides a list of available options in response to each question.

The user may choose to map any of the following variables: age class, volume, structural stage, seral stage, cover type (grouped in one of three ways), attributes, road maps, road density, road buffers, interior habitat, patch sizes, area disturbed or affected by management, frequency of disturbance, probability of disturbance, management systems and BEC. These variables allow the user to see the state of the landscape at a specified point in time during a single Monte Carlo simulation from any scenario. ‘Area disturbed’ displays the location of disturbance events or management activities over any period of time in a single Monte Carlo simulation. Either natural disturbances or management events may be displayed, using any combination of disturbance types selected by the user. Similarly, “Frequency of disturbance” maps the number of times that each landscape simulation unit was affected by any of the selected disturbance types during the user-defined time period. The final variable, “probability of disturbance,” summarises the results of all the Monte Carlo simulations available for the selected scenario. This variable shows the proportion of all Monte Carlo simulations in which each polygons in the landscape was disturbed during the specified period.

As the user answers each question, the tool builds a query that gets sent to the database and returns the records for mapping. The maps automatically appear, complete with information about the static polygons (the non-projectable polygons), and a legend appropriate to the chosen variable. In some landscapes, some minor modifications to legends may be necessary. For example, the definition of the static polygons may change between landscapes, so the legend would need to change to reflect the new landscape.

Each time a new mapping request is made for the same landscape, the user may choose whether to display the results in a new map window, display the results on a new copy of the map in the same window, or display the results on the same copy of the map as was used for the previous request. These choices give the user the options of comparing results side-by-side, overlaying different map results, or creating a single map database file containing all of the requested data for use in another application.

6.2 Summary results

In many cases, users may be interested in comparing broader differences between runs, such as the overall age class distribution at the same point in time in two different scenarios. The TELSAs Graphical Display tool allows users to select from a number of different options, and provides options for both displaying results in graphs or as tables of summary statistics. Both the graphs and the statistics can be sent directly

to the printer. In addition, graphs can be saved as metafiles that can be imported into a document, or the information in the graph can be saved and imported into a different graphics package.

6.2.1 Graphical results

The graphical display is quite flexible. It allows users to choose from several different categories of graphs, and then customise the specific results within each category. All results and options are read from the database to maintain long-term flexibility. Output is produced in MS Excel format allowing users to cut and paste data, graphs and tables directly into other analysis software or into presentations and documents.

In most cases, users generally pick the type of output they want (e.g., disturbances or age classes, etc.), and then select one or more runs, Monte Carlo simulations, BEC variants, planning zones, and specific options. The tool creates a query from the information that was selected and gets the appropriate results from the database. In all cases, the interface will draw between one and four graphs and decide how to divide the information between the graphs. The general graphical options (found under the “Graph” menu) are:

Disturbances

All disturbances are shown as graphs over time, with the area (ha) or volume (m³) disturbed on the y-axis. If the user requests “ALL” Monte Carlo results, for a particular disturbance type, the interface will create graphs showing the highest value, the lowest value, and the average value for each time step in addition to graphs with mean values \pm SE.

Polygon Attributes

For polygon attributes the model graphs their total amount in the landscape over time

Numerical Attributes

For numerical attributes the model graphs their total amount on the landscape over time.

Age

Ages are graphed as one or more line graphs over time. In all cases, the y-axis shows either area (ha) or volume (m³) within a user specified age range. Several age ranges can be graphed on the same chart. As with disturbances, when multiple Monte Carlo simulations are graphed – minimum, maximum and standard error values are also shown.

Seral Stage

Seral stages are graphed over time, with the y-axis showing the area within a user specified seral stage range. Several seral stage ranges can be graphed on the same chart. As with disturbances, when multiple Monte Carlo simulations are graphed – minimum, maximum and standard error values are also shown.

Roading

This report graphs the length of roads of specific ages and status (active/inactive) on the landscape over time.

Cover Type

Bar graphs of the distribution of the landscape into different cover type groupings will be produced. The groupings are all defined by the user in the database. Because this graph reads the detailed state output table, this graph can take several minutes to produce.

Disturbance Sizes

This report shows bar graphs with the number of incidents and total area in each size class and also shows a scatter plot over time with the actual sizes of the disturbance events plotted.

Patch Sizes (only if spatial analysis has been run)

The patch size distribution, by the size classes defined by the user (see Section 6.1.1)

Interior Habitat (only if spatial analysis has been run)

The distribution of patches of interior habitat, into the size classes defined by the user.

Interior Ratio (only if spatial analysis has been run)

This is the ratio of the amount of interior habitat in the landscape to the total amount of available area in the landscape.

6.2.2 Static information

This report summarises the area in the landscape as it is broken down by Planning Zone and BEC or PVT components.

7.0 References

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Appendix 1: Glossary

BEC	Biogeoclimatic Ecological Classification (an ecological stratification similar to PVT)
Ecological classification	A way of stratifying the landscape based on vegetation characteristics (e.g., BEC variants in BC or PVTs in the US).
Landscape	The maximum extent of the analysis and the area for which the base data are gathered. This will typically be an area of on the order of 100,000 hectares.
Management unit	The smallest unit that will be considered in any given harvesting activity. A management unit will consist of one or more minimum polygons.
Management system	A list of one or more activities that will be done in sequence on a given area.
Minimum polygon	The smallest spatially explicit unit. Polygons will be of variable size and shape.
Operational unit	A type of planning zone that is used as part of the harvesting algorithm. These represent major areas that are managed. Each minimum polygon and management unit will belong to one operational unit, and each management unit will be wholly contained within an operational unit.
Planning zones	Areas in the landscape which share common resource management objectives and management prescriptions, e.g., riparian zones, community watersheds, parks.
PVT	Potential Vegetation Type (an ecological stratification similar to BEC variant)
Scenario	A set of parameters, including natural disturbance probabilities and management options, that is defined for a run of the model. A single scenario may be simulated numerous times to account for random variation in natural disturbances.
Site index	A measure of site productivity, typically expressed as average top height (in metres) of the 100 largest (by dbh) trees per hectare at age 50 years.
TELSA	Tool for Exploratory Landscape Scenario Analyses
VDDT	Vegetation Dynamics Development Tool, an independent windows-based program used to define and test successional pathway diagrams (Beukema, Kurz and Pinkham 2002).

Appendix 2: Examples of Structural Stage Definitions and Descriptions

Structural Stage	Definition	Description
1. Stand Initiation	Growing space is reoccupied following a stand replacing disturbance (e.g., fire, harvest) typically by seral species.	1 canopy stratum (may be broken or continuous); 1 cohort seedlings or saplings; grass, forbs, shrubs may also be present with early seral trees.
2. Stem Exclusion: Open Canopy	Occurrence of new tree stems is excluded (light or moisture limited); crowns abrading, canopy closed.	1 broken canopy stratum; 1 cohort; trees excluding new stems through competition; poles, small or medium trees; understorey shrubs, grasses, forbs may be present.
3. Stem Exclusion: Closed Canopy	Occurrence of new tree stems is excluded (moisture limited); crowns open growing; canopy broken; can be maintained by frequent underburning or management.	Continuous closed canopy; one or more canopy strata; one cohort; lower strat(a), if present, are same age as upper strat(a) poles, small, or medium trees; understorey shrubs, grasses, forbs may be present.
4. Understorey Reinitiation	Second cohort established under older typically seral overstorey; mortality in the overstorey creates growing space for new trees in the understorey.	Broken overstorey canopy; > 2 canopy strata; 2 cohorts; overstorey is poles, small, medium, or large trees; understorey is seedling, saplings, or poles.
5. Young Forest Multi Strata	Several cohorts have established under the influence of management, or fires with mixed lethal and nonlethal effects, or by insect and disease group killing; seral overstorey large trees are generally absent due to harvesting or other disturbance.	Broken overstorey canopy; > 2 canopy strata; > 2 cohorts; large trees absent in the overstorey; stand characterised by diverse horizontal and vertical distributions of trees and tree sizes; seedlings, saplings, poles, small, and medium trees.
6. Old Forest Multi Strata	Multicohort, multistrata stands with large, old trees.	Broken overstorey canopy; > 2 canopy strata; > 2 cohorts; medium and large trees dominate in the overstorey; stand characterised by diverse horizontal and vertical distributions of trees and tree sizes; all tree sizes may be present.
7. Old Forest Single Stratum	Single stratum stand of large, old trees. No or few young trees in the understorey; park-like conditions resulting from nonlethal natural or prescribed underburning or other management	Broken or continuous canopy of large, old trees; 1 stratum, may be single or multicohort; overstorey medium or large trees; understorey absent or seedlings or saplings; grass, forbs, shrubs may be present in the understorey.

source: Kevin O'Hara and Penny Latham (pers. comm.)

A cohort is defined as a group of trees arising after a common natural or management disturbance.