ful for diagrammatic planning, such as designing harvest and silvicultural blocks, and as a geographic sketchpad for note-taking in the course of planning activities. The SBWDSS could use this functionality in an ArcView version of one of its tools known as the Protection Planning System (PROPS), which is currently implemented using ARC/INFO. This system produces a thematic forest stand map shaded according to the priority it has for receiving protection against spruce budworm, calculated as the timber supply benefit (m^3/ha) of protecting the stand at the scheduled time of harvest. Essentially, it is the additional volume gained if the stand is protected. The planner could use the information on this map to assist in drawing spray blocks for an aerial insecticide program, using the ArcView drawing capabilities. During this activity, the planner would attempt to create blocks that include the highest priority stands, given the constraints of the aerial application procedure.

The geographic analysis capabilities of ArcView allow examination of relationships between themes, using theme-on-theme operations like point-in-polygon, line-in-polygon, and polygon-on-polygon. For example, to create a spruce budworm susceptibility rating, one could overlay the two previous years of defoliation, budworm population data from egg-mass collections in the current year, and the spruce-fir stands from the forest inventory.

With the spatial join capabilities of ArcView, data that refer to the same geographic location, even if they were at different scales, could be joined to determine relationships that might otherwise be difficult to find. Aerial defoliation themes for the past ten years could be joined to an ecological zone theme, allowing comparison of historic insect activity among different zones. Areas of interest arising out of this analysis could then be selected and converted into new themes (either temporary or permanent), and further compared with other information such as current vegetation.

Spatial analyses like this are typical applications for GIS, but normally require significant software expertise and programming of a specific procedure using the appropriate commands. This can be completed in ArcView in much less time, using the point-and-click user interface.

In addition, simple proximity analysis can find relationships between two sets of features, based on proximity. For example, displaying mature and overmature spruce-fir stands within a given distance of other spruce-fir stands might identify clusters of budworm susceptible forest.

Dynamic Data Linking and Programmability

A "hot link" is a hypertext-like facility that allows other data sets or programs to be attached to geographic features and accessed or initiated upon request, in the same way that text documents use hypertext to link to other documents.

For example, a spruce budworm defoliation theme might be displayed at a scale of 1:50 000. When a defoliation polygon is selected with the mouse, the hot-link capability could display a second View containing a theme of stand species composition at 1:12 500 scale. In effect, we are viewing more detailed information, for a second theme, that is "beneath" the defoliation polygon classified as severe. This can be thought of as "drilling-down" into the map for more information. Another example appears in Figure 5, where the hot-link automatically displays a scanned photograph representative of the stand selected by the user. The photo could be included in a database of photographic images classified according to stand attributes such as species composition, maturity, site productivity, or insect defoliation history.

Hot links can also be used to execute ArcView scripts, launch sophisticated applications such as ARC/INFO, or run custom ecological models. For example, a pest vulnerability rating system could be developed that is executed via the hot link when the user clicks on a stand. It could consist of a short program that applies a set of rules, coded in ArcView script or a conventional programming language like C++, to determine the stand's vulnerability to a particular insect. Hot links could also be used to extend

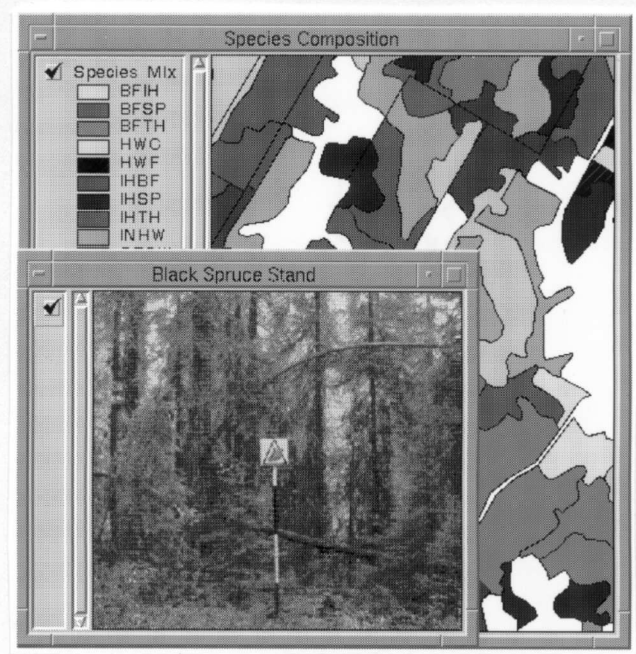

Figure 5. The View window appearing in the background contains a species composition map. When the user selects a black spruce stand on the map, a digitally scanned photograph of a stand having similar composition is displayed using the hot link facility, as shown in the foreground.

ArcView's functionality by executing an ARC/INFO procedure to perform a complex spatial analysis operation, using the current stand as input.

One of the keys to an effective DSS is allowing the decision-maker to analyse a result or 'answer', and determine precisely how that result was derived. This can be done by providing access to both the input data and intermediate results that were utilized in calculating the final results. With ArcView, any feature can be identified by clicking on it using the "info" tool from the tool bar, which displays all data stored in the database for that feature. Any theme based on derived or calculated attributes can be explored to see the underlying data. Storing all input and intermedate results for a model or DSS tool, and referencing it to the stand, is a good DSS design guideline no matter what the software.

Avenue is the name of the object-based programming language used to write ArcView scripts. Object-based, a subset of object-oriented programming, models aspects of the real-world as objects that contain both data and procedures related to the data (Taylor 1991). Avenue employs a client-server architecture, and supports inter-application communication (IAC) on all platforms, facilitating the integration of other software with ArcView so that a collection of programs can be used as a single system. Avenue also allows customization of the ArcView product itself, as all of the objects in an ArcView Project can be accessed and modified through Avenue scripts. With this programmability, ArcView can be viewed as an application of Avenue.

Avenue also supports programmable integration with ARC/INFO. It appears that ARC/INFO is moving toward server functionality, supplying advanced GIS procedures, with ArcView providing the user interface to these services. This is the essence of a client-server architecture, with ArcView as the client and ARC/INFO as the server.

Conversely, a customized database application written in Microsoft's Visual Basic, such as a permanent sample plot database, could communicate with ArcView to obtain a map of plot locations and geographic query capabilities. In this example, the Visual Basic application is the client and ArcView serves mapping capability to it. ArcView provides the IAC capability through standard protocols: RPC on UNIX, dynamic data exchange (DDE) on MS-Windows, and Apple Events on Macintosh.

Use of ArcView in the Spruce Budworm DSS

We have used the Inventory Projection System (IPS), a tool within the SBWDSS (DeMerchant 1994, MacLean and Porter 1996), to demonstrate the use of ArcView in forest pest management DSS. Forecasting the future is a fundamental part of managing a forest, and IPS allows a forest manager to visualize future forest conditions by simulating stand development, spruce budworm outbreaks, and protection. The idea behind IPS is to provide a tool that allows forest managers to explore the possible futures resulting from various insect outbreak and protection combinations that could occur on their land base. The system was originally developed using the ARC/INFO macro language (AML) and the C programming language, with the projection engine written in C, and AML used for the user interface and spatial data handling (DeMerchant 1994). IPS has been re-implemented using ArcView as the user interface, and to perform the spatial data handling, mapping, and graphical charting. The user specifies several simulation parameters, which ArcView passes to a C program that forecasts the inventory (MacLean and Porter 1996). The forest inventory data are converted to a shapefile that stores both the inventory stand attributes and the new attributes generated during the simulation.

ArcView functionality makes visualizing the before-and-after results of IPS runs easy. Figure 6 displays the current spruce-fir volume before a projection, and spruce-fir volume 30 years later after a severe spruce budworm outbreak with no insecticide protection applied. The darker shades represent higher volumes of spruce-fir, indicating there would be substantially less spruce-fir volume in these stands following the outbreak. IPS includes several themes that can be displayed for current or projected data, including species composition, stand age, total volume, hardwood volume, volume change, and stand susceptibility to budworm (MacLean and Porter 1996). Being able to generate maps that reflect the changes in several landscape attributes as a function of alternative management strategies is a powerful capability in the hands of a forest decision maker.

ArcView can be used to summarize tabular information by calculating statistics, linking them to the spatial information and, in effect, adding new data to the geographic features. Maps are a useful medium for viewing spatial data, but graphical comparison of summarized information often makes changes clearer. Figure 7 shows an IPS comparison of area by stand species class (determined according to the relative abundance of each species in the stand), before and after a projection 30 years into the future, under a scenario specifying a severe spruce budworm outbreak with no insecticide protection applied.

Conclusions

ArcView is an effective development tool for forest and pest management DSS. Its GUI makes it easy to display maps and charts and to use the display and query capabilities required for natural resource DSS. The dynamic linking of different representations of geographic data and the flexible hot-link capability can be used to view data from several perspectives and to explore potential relationships between data. Because much of today's spatial forest

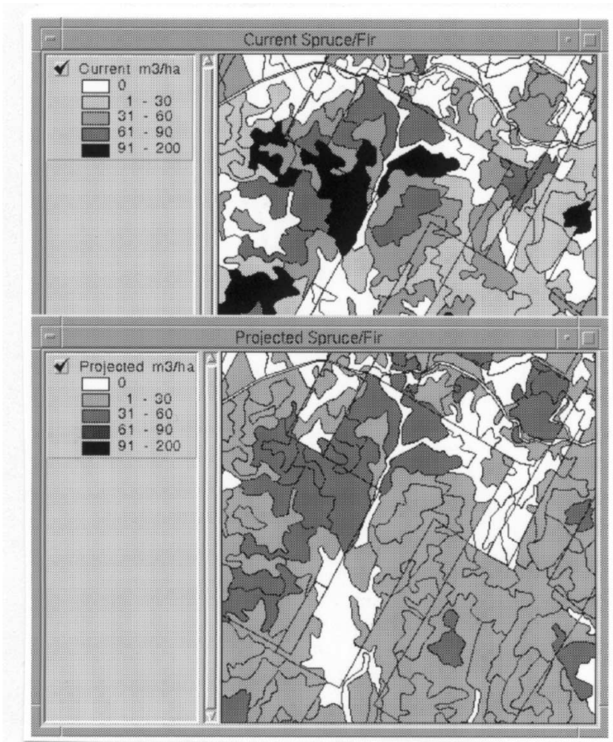

Figure 6. Two View windows displayed simultaneously allow visual comparison of stand attributes after a simulation using the IPS tool in the SBWDSS. The upper map shows the initial spruce-fir volume (m^3/ha) for an area of forest land. The lower map displays the spruce-fir volume, for the same land area, after being projected 30 years into the future, following a spruce budworm outbreak with no insecticide protection applied. Since darker shades represent higher volumes, a comparison of these maps indicates significant spruce-fir volume loss at the end of the simulation.

data is being used in the ARC/INFO GIS, Arcview's compatibility facilitates a quick start-up for experienced users. Extensibility is achieved by ArcView's capability to integrate, through standard communication protocols, with other software, allowing it to be a flexible tool in a software toolbox. Avenue, its object-based scripting language, provides developers and users with a complete programming environment to customize the user interface, add functionality, and create custom applications utilizing ArcView as either a client or a server.

How can ArcView be used to package DSS functionality? Avenue scripts can be written to provide all themes, charts, layouts, and other displayable objects. A setup script can be provided to configure the DSS tool with the user's data and to supply custom legends for themes which could be modified by the user as desired. An ArcView project file can be developed that customizes ArcView as a user interface for specific pest/ forest management DSS applications. Each DSS tool could then be part of a separate project file, but could operate using a common look and feel. There is no data duplication here, because an ArcView project includes only links to the data it requires.

ArcView is indeed a generic DSS tool. The job of DSS developers is to provide scientific, derived, and modelled information, in clear, understandable formats that allow decision makers to assess the costs, benefits, and consequences of management actions. As a generic, customizable, easy-to-use tool, ArcView provides much of the user-interface and data handling functionality needed for DSS development.

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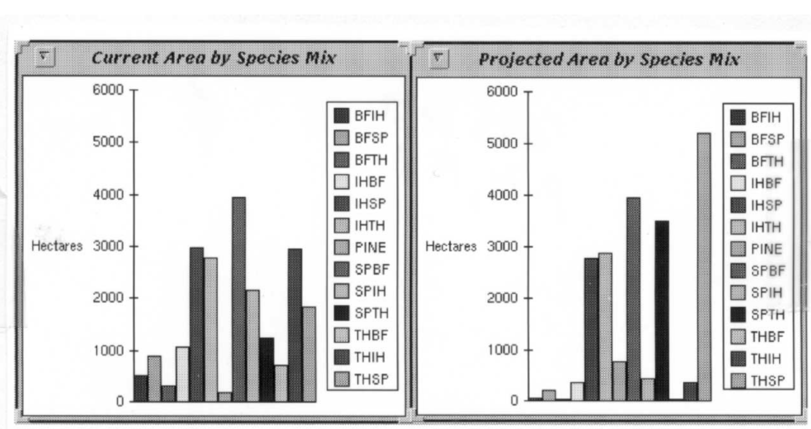

Figure 7. Two bar charts comparing area by species class before and after a projection of the forest inventory into the future, undergoing a simulated spruce budworm outbreak with no insecticide protection applied.

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