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The multiple roles of environmental data visualization in evaluating alternative forest management strategies

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Abstract

Forest management decisions are often based on long-range projections of future forest conditions. These conditions and effects can be complex and difficult to understand for those not trained or experienced in forest management. Modern computer-based environmental data visualization systems have been found to be of considerable assistance in this context. Cost effective computer visualization techniques have made it increasingly feasible to visually represent environmental conditions that are otherwise only represented by abstract statistics. Currently, members of the Collaborative for Advanced Landscape Planning at the University of British Columbia are investigating the effectiveness of various environmental data visualization methods as applied to land management decision-making processes. Preliminary results of this work are discussed and the implications of the use of these technologies in a variety of contexts are examined. This work allows forest and environmental modelers to see statistical outputs in ways never before accessible to them and by so doing to gain insights into the assumptions and limitations of their models. Interdisciplinary forest management teams may more effectively reach a mutual understanding of expected changes in forest conditions, and of the effects of biophysical agents on those conditions. Additionally, increased understanding and communication between disciplines are facilitated by these technologies and a shift from weak to strong interdisciplinary research can be realized. By observing precise, near-photo realistic visualizations, concerned public audiences also may better understand and appreciate the motivations and intentions of pro-

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posed forest management actions, though there is a risk of misinterpretation of the visualizations or misplaced belief in the underlying models. These and other potential uses of environmental/data visualizations in the context of sustainable forest management are reviewed and evaluated using examples from recently completed and ongoing pilot projects.

Keywords: Environmental visualization; Sustainable forest management; Decision support; Ecological modeling; Public involvement

1. Introduction

In recent years our knowledge of forest ecosystems has greatly expanded. This has occurred in the context of frequent shifts in societal values. Given these objective realities, it is no wonder that landscape management decision-making processes are often mired in confusion and obfuscated by controversy. This trend will certainly continue given increasing social diversity stemming from better transportation and trading systems that define our ever-shrinking world. Scientific knowledge of the world around us continues to be uncovered at an exponential rate and long gone are the days of the great generalists such as Galileo, simply because the depth of knowledge in each and every discipline precludes any one individual from possessing the requisite understanding across disciplines. As a result of this, modern day scholars that wish to address problems that cut across disciplinary bounds must embrace interdisciplinary research. While this approach is far from a panacea, in many ways it represents our best hope for integrating the increasing depth of knowledge of forest ecosystems with the values of modern societies.

Understandably, this shifting focus towards interdisciplinary research has triggered a great number of possibilities for the future and an even greater number of management alternatives to be used in the realization of those desired futures. This, in turn, has led to an increasing application of computer models in the hopes of managing the complexity of the decision-making space within which we now find ourselves. It is to this end that we have developed strong interdisciplinary links amongst researchers at the University of British Columbia and have participated in a number of focused research projects aimed at exploring some of these problems.

In this context, members of the Collaborative for Advanced Landscape Planning (CALP) at UBC have explored the use and potential of sophisticated environmental visualization technology in interdisciplinary forest management planning and decision support. This ongoing developmental work has included progress in a number of areas aimed at increasing the speed, automation and accuracy of environmental visualizations, to assist both experts and the lay public in understanding the important but complex issues involved in sustainable forest management. In addition, we have focused a great deal of attention on the technical aspects of constructing landscape visualizations, in evaluating the efficacy and applicability of these visualizations in a variety of natural resource related contexts, and in investigating the validity and ethical constraints around their use.

The purpose of this paper is to briefly review the context, potential benefits and current limitations of visualization in forest decision support; describe the visualization techniques and study methods under development at CALP on sustainable forestry projects; and discuss initial results and observations drawn from these ongoing research projects.

2. The context for environmental/data visualization in decision support for forest management

Over the years great advances have occurred in the area of environmental visualization. Early visualization systems for forest management applications (e.g., Travis et al., 1975; Myklestad and Wagar, 1977) were useful for the professional forester, but the computer-generated graphics were typically quite abstract. This basic approach was greatly enhanced in later systems (e.g., Daniel et al., 1988; Heasley, 1990), but the resulting visualizations were still rather abstract, clearly being the result of computer rendering. However, the degree of realism currently available from purely data-driven renderings is quite astounding and has opened up new possibilities for increasing the representational validity of today's environmental visualizations (Daniel and Meitner, 2001). It has been argued that realistic landscape visualizations are particularly important, if not essential, in addressing certain social implications of site-specific forest management actions (e.g. Sheppard, 2000). These advances in realism, in conjunction with recent progress in real-time near-photo realistic rendering (Cavens, 2002), offer the promise of even greater simplicity in interacting with these systems on the user side. Even more promising is the potential to solicit more accurate emotional responses due to increased realism, as well as facilitating a greater degree of spatial understanding of the underlying data due to the increased interactivity they afford (Lum et al., 2002).

Modern data visualization systems focused on forest and land management issues typically translate quantitative, data projections of future (or desired) forest conditions into concrete visual representations. In this context, data visualization emphasizes systematic, readily traceable links between forest biophysical data and the features presented in the visualization (Orland, 1988, 1993; Daniel, 1992).[1] However, the problems related to feeding these systems with appropriate data are compounded when spatial and temporal navigation is left to the user. It is for these reasons that we have set out to streamline the flow of data from a variety of sources in order to facilitate the creation of environmental visualization for each of these projects.

Also, it is no longer necessary to spend tens of thousands of dollars on specialized hardware that was needed only a decade ago to produce high-quality renderings of proposed future conditions. A plethora of new software is now available at ever decreasing prices that allows individuals with only moderate levels of computer skills to create convincing environmental visualizations. In fact, many applications such as geographic information systems (GIS) and computer aided drafting (CAD) now have tools built into them to allow for the creation of perspective view output. For example, programs such as Viewscape 3D's Ecoviewer offer not only the ability to fly over a digital terrain built using data in

[1] For more information on the techniques used in the field of environmental visualization see McGaughey (1998).

real-time but also allow for the user to interactively edit the data underlying the visualizations. Given this trend toward cost effective, increasingly powerful software and systems it might be reasonable to ask why the use of visualizations is not more prevalent than it is today.

The answer lies predominately in the lack of high-quality data needed to support these applications. This is especially true when attempting to represent the future. In this case, it is not sufficient to rely on off-the-shelf data products such as digital elevation models or forest cover information. Instead, one must extrapolate data representing aspects of the environment to be visualized into the future. While much has been written about the use of visualizations in environmental planning and management (e.g., Appleyard, 1977; Malm et al., 1981; Sheppard, 1989; Orland, 1992; Orland et al., 1992a; Bishop and Karadaglis, 1997), including applications designed specifically for support of forest health planning and management (e.g., Baker and Rabin, 1988; Daniel et al., 1990; Lynch and Twery, 1992; Orland et al., 1992b), little practical application has occurred outside of the academic context over the years.

Additionally, the technological barriers of achieving increased realism, responsiveness (interactivity) and immersion (which can be collectively referred to as virtual reality), have received the lion's share of attention as opposed to the less appealing problems of how these technologies will be used in common practice. While we do believe that any serious attempt at representing reality should excel at all three of the aforementioned qualities, it is also important that the technologies are utilized to their fullest potential. Real progress in bringing about the application of environmental visualizations to support the decision-making process would greatly extend current capabilities; however, if this is to occur we believe that four challenges must be met:

(1) High-quality biophysical data must be provided in a timely manner,
(2) Environmental visualization systems must be increasingly tied to scientific models in order to produce credible output,
(3) The systems must clarify and if necessary simplify environmental information and relationships, and
(4) These systems must find methods to deal with the underlying uncertainty of the predicted data used to create environmental visualizations though there is much debate on how uncertainty in predictive modeling should be represented (e.g. Orland and Uusitalo, 2001).

2.1. Description of CALP visualization system

At CALP, we have focused our recent efforts on more fully integrating state-of-the-art forest modeling programs and off-the-shelf rendering platforms, in order to explore these challenges and create tools and imagery for further testing in applied and experimental settings. In this section of the paper, we outline the visualization system as a whole in relationship to the contributions of our multi-disciplinary colleagues in these research projects, and begin with a brief discussion of the system components represented in Fig. 1.

The CALP Visualization System was created to address some of the goals of a more widely usable visualization system. The CALP Visualization System is a computer program

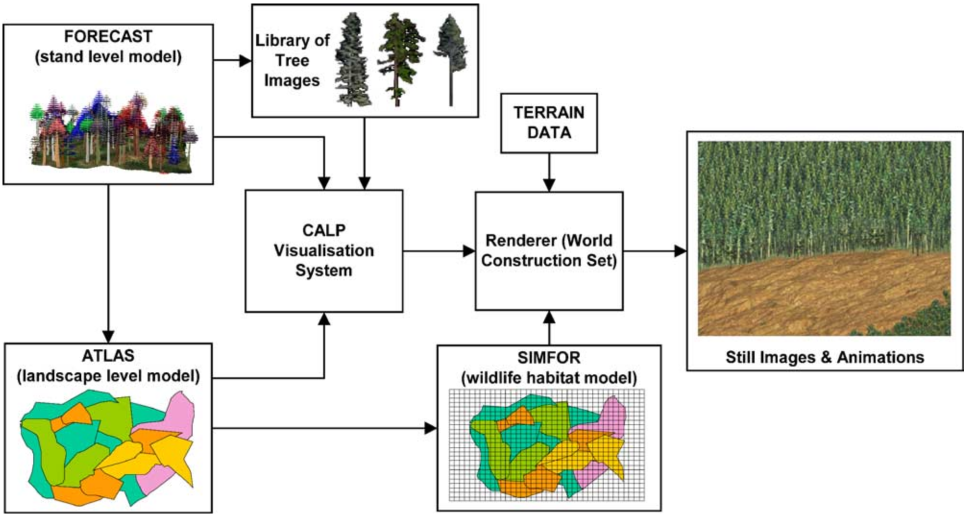

Fig. 1. Flow chart showing the overall visualization process used.

that links a number of forestry modeling programs such as FORECAST (an ecosystem-based, stand-level, forest growth simulator), FPS-ATLAS (a forest-level harvest simulation model) and SIMFOR (a decision support tool designed to help managers and researchers evaluate the impacts of forest harvesting scenarios against landscape and habitat indicators). Outputs from these programs are then synthesized by this visualization system and sent to a rendering engine. The strength of this approach is that the CALP Visualization System can be adapted to accept information from any relevant model and produce output for many different rendering engines. However in this specific case 3DNature's World Construction Set 5.0 was used as the rendering engine and the aforementioned modeling programs were used on the input side.

Because this work has been predominately focused on aspects of forest management within a sub regional context in British Columbia (see Sheppard and Meitner, 2005 for a fuller description of the application of this system), and because of the importance of the temporal dimension to forest management decisions, tools were needed to model both stand dynamics and landscape-level change. FORECAST was used to provide our visualization system with the necessary parameters for defining species composition, stand densities, tree height, and crown ratios. This model, developed by the Forest Ecosystem Management Simulation Group at the University of British Columbia (http://www.forestry.ubc.ca/forestmodels/), was designed to accommodate a wide variety of harvesting and silvicultural systems in order to compare and contrast their effect upon forest productivity, stand dynamics, and various biophysical indicators of non-timber values (Kimmins et al., 1999; Seely et al., 1999). The model uses a hybrid approach whereby local growth and yield data are combined with other data to derive estimates of the rates of key ecosystem processes related to the productivity and resource requirements of selected species.

For the landscape-level modeling, FPS-ATLAS was used to provide the visualization system with information about where and when management activities would occur in the area being modeled. FPS-ATLAS was designed to schedule management activities according to a range of spatial and temporal objectives and forms the basis of our ability to visualize a range of desired forest futures (Nelson and Wells, 1996; Nelson, 2001). A number of possible policy dimensions can be explored using this tool such as the rate of harvest flows, the opening size of a harvest block, targets for seral stage distributions, etc.

These two programs work in concert with each other. FORECAST providing FPS-ATLAS with appropriate growth and yield information based on the harvest and silvicultural information provided by FPS-ATLAS. The CALP visualization system takes output from both programs, concatenates, parses and reinterprets these data by means of a Perl script and generates text files to automate the set up of World Construction Set "ecosystems" (a term used by World Construction Set to denote a contiguous and homogeneous vegetation polygon) that in turn allow us to visualize the area being modeled.

Information regarding species composition within the stands is used to select appropriate tree images from the CALP Tree Library. This library of tree images has been amassed over the last 5 years and includes nearly 200 images of tree species by age and condition common to the province of British Columbia and the Pacific Northwest. Once the appropriate images are selected, they are arranged within the boundaries of the stand according to species density information. World Construction Set uses a commonly known technique called billboarding to populate the terrain within the stand boundaries with this carefully constructed array of tree images. This technique allows for a large number of trees to be represented in a highly realistic fashion within the three-dimensional model while minimizing the number of polygons. In fact, if any single advance in computer technology has changed the face of forest visualization, it has been this technique because it has brought a degree of realism to these data-driven visualizations that was nearly impossible prior to its advent.

Once the basic modeling of a given forest management scenario was accomplished and before visualizations were created, the scenarios were typically handed over to a number of evaluative models (represented in Fig. 1 by the SIMFOR box) that would help us to estimate the impacts of the scenario along a number of socially relevant dimensions. One of these dimensions of great importance has traditionally been wildlife habitat and to address this concern SIMFOR was brought to bear on the problem. SIMFOR is a decision support tool designed to help managers and researchers evaluate the impacts of forest harvesting scenarios against landscape and habitat indicators and was originally developed by a team of researchers at the Centre for Applied Conservation Research within the University of British Columbia (Wells et al., 1999). This program reports on general trends in selected indicators of forest structure and function through space and time, which can then be spatially draped over the environmental visualizations as a color map allowing for the visualization of selected non-visual information as seen in Fig. 2.

A number of visualization products have been developed with this system over the last few years and in relationship to the projects described so far the static outputs can be divided into three groups (adapted from Danahy, 1999). The first group is comprised of visualizations that focus on strategic overview. These images are typically rendered from an elevation higher than 200 m and at a significant distance from the subject matter

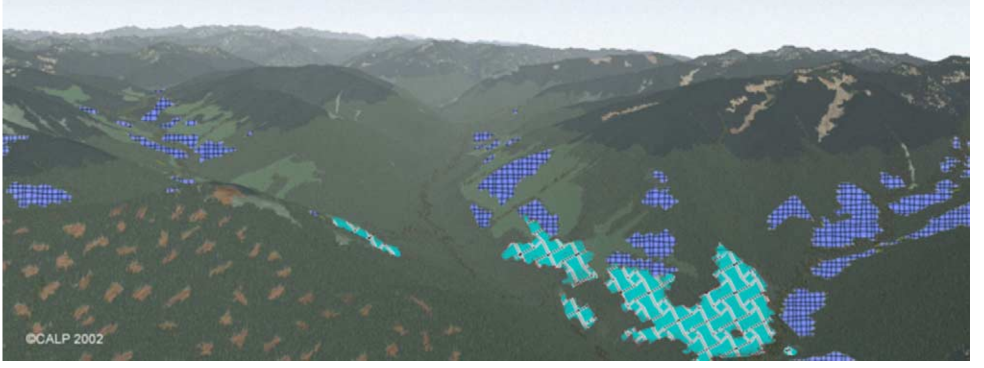

Fig. 2. An example of habitat quality information draped over a typical environmental visualization.

being portrayed. Foreground elements are rarely depicted. The second group of images is typified by visualizations that attempt to communicate spatial patterns or arrangements. Standard elevations for cameras used in rendering these images are generally between 1 and 200 m. Foreground elements are accommodated but are typically minimized in prominence as distances from subject matter are normally optimized to accurately portray the scale of spatial patterns being shown. The third group is represented by those visualizations that endeavor to convey some sense of presence or "sense of place" and often attempt to mimic a fuller range of information typically available to the human sensory input apparatus. Most commonly the elevation of the camera would be at eye level but in some cases this rule may be modified to achieve other goals (as in Fig. 3). The subject matter is usually quite close and at a human scale, and issues of perspective distortion are typically controlled for. Examples of these three types of visualizations can be seen in Fig. 3.

3. Results and discussion

Essentially the CALP visualization system is a means to orchestrate the flow of large quantities of data needed to create accurate portrayals of forested landscapes based on high-level policy decisions governing the likely path of our collective forest futures. However, this is no simple task and requires the inputs of a number of experts in forest management, landscape planning and a variety of related ecosystem management specialists such as hydrologists, botanists, and ecologists. The reason for this is that these higher-level policy decisions must be reduced to a set of simplified rules that can be implemented within the limitations of the modeling systems brought to bear on these problems. Sometimes this reduction is straightforward and there is little contention among experts about how a given policy dimension will be formulated. However, this is not often the case and a number of experts are needed from a variety of disciplines to discuss and debate the subtleties of this implementation. Indeed, a well-rounded interdisciplinary team must be involved in this evaluation process.

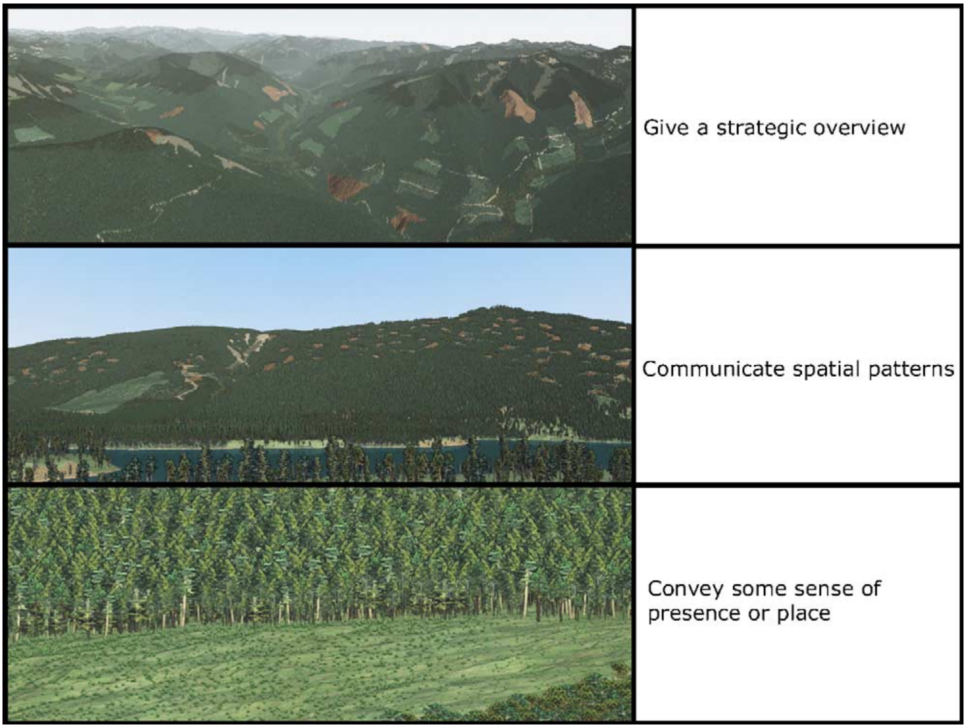

Fig. 3. Examples of three distinct types of environmental visualization outputs based on camera position.

3.1. Research applications

This refinement of evaluation through collaboration has been one of the most valuable, and in some ways unintended, benefits of this work. Because these visualizations allow us a window into the future, as interpreted by the expert-led modeling process, we were able to directly assess the face validity of a number of our assumptions. Of course this is limited to effects on biophysical variables that in some way modify the visual aspects of the ecosystem but on a number of occasions our visualizations have given insights into aspects of the modeling efforts that would have been otherwise unavailable to us. One example of this was a series of visualizations rendered from an oblique aerial camera position that uncovered a number of unmanaged stands that were not being dealt with by the models and therefore had no data associated with them. These polygons with missing data were rendered as non-vegetated gray patches as seen in Fig. 4.

While this omission represented no direct error or flaw in the modeling process (since the stands were outside of the management context being modeled, i.e. private land) it did serve to illustrate the bounds of our model, thereby increasing the team's overall understanding of the project. Additionally, individual team members were able to see the output of their models in new ways, often yielding new insights into the nature of the models themselves including limitations, assumptions and at times errors. For example, when the output of

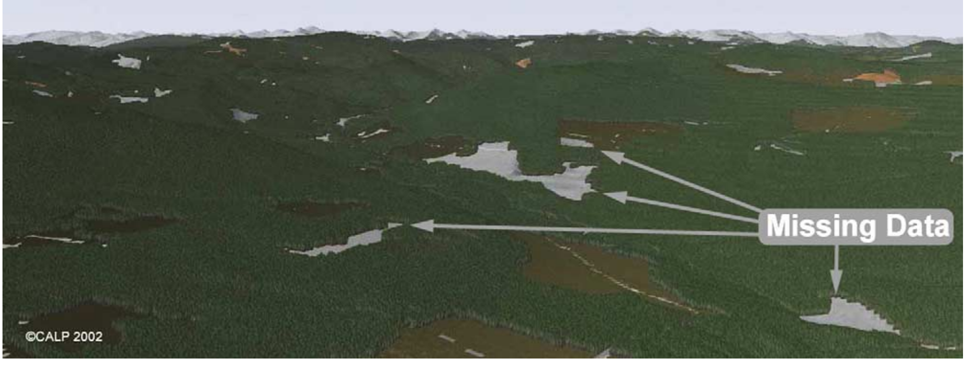

Fig. 4. Aerial oblique visualization of the Highhat Valley in Northern BC showing missing data.

a initial habitat suitability model was draped as a raster on top of the near-photo realistic visualizations (e.g. Fig. 4), it quickly became apparent that the chosen cell size was too large to be of use in relating back to operational forest management based on the size of typical management blocks in the area of study. In response to this insight the granularity of the model was decreased by reducing the cell size, thereby increasing the relevance of that work to other aspects of the project. This was especially helpful to other team members who were not as intimately familiar with the models as their creators, and allowed for a more consistent and accurate understanding of the suite of models to be promulgated throughout the team. When involved in interdisciplinary efforts such as these, this enhanced level of understanding can lead to more rapid innovation, increased dialogue between team members (often among disciplines that are philosophically quite removed) and fewer misunderstandings overall, which ultimately yields a more productive research environment.

3.2. Public forum applications

So far, we have addressed the benefits of environmental visualization within the research group and while these are certainly significant, they were not really the primary focus of this work. Ultimately we wanted to investigate the potential of these technologies to disseminate information to the public and to act as vehicles for evaluation and feedback regarding possible forest management scenarios. This feedback can then be used in an iterating loop between the public and management professionals to refine the preferred set of forest management scenarios to further meet the needs and desires of both groups. CALP has used these visualizations in a number of public forums within the context of interdisciplinary research projects aimed at sustainable forest management. While the analysis and interpretation of research findings from these pilot applications of visualization are still underway, some general observations stemming from these studies can be made. These may inform practitioners already experimenting with visualization in practice and guide further research.

The simplest of these public forums employed to date would typically be an information download session, where the context of public interaction was more one sided, as in a presentation aimed at disseminating information about ongoing modeling efforts. In this context, visualizations appear to be most helpful, as they tend to make the modeling outputs more salient to the average attendee. In fact, of the 45 participants involved in the study described by Sheppard and Meitner (2005), 91% stated that the visualizations were either "very helpful" or "moderately helpful" on a five-point scale when asked to evaluate various aspects of the decision-making process they were involved in. Often the presentation sparked considerable discussion about the origin of the images and how they related to the ongoing modeling efforts.

Another effect of showing these visualizations was the ability of people to recognize specific locations and/or features of the environment in relationship to their knowledge of the area. One striking example of this was the presentation of an animated fly-through of the study area, the Lemon landscape unit located in the Arrow Timber Supply Area of southern British Columbia. When local stakeholders were shown this video animation as part of our investigations, most participants made comments about specific and meaningful features of the biophysical landscape as they virtually passed by them. This enhanced the credibility of the visualizations and served to better anchor the visualizations of specific viewpoints as the video would fly them from one to another, thereby minimizing the tendency for participants to treat each individual viewpoint in isolation when considering the visual ramifications of proposed management activities. Obviously this effect is limited to public groups that have lived in and around the area being modeled, but the ability to facilitate a general spatial orientation of unfamiliar areas has also been observed when non-local publics are exposed to this type of visualization. Additionally, in the Arrow study, the animation method caused people to question the selection of static viewpoints and nearly all of them agreed that they would like to have the ability to interactively view proposed actions from a multitude of angles.

Related to this issue of spatial orientation is the idea of temporal orientation. In the context of forest management it is imperative that individuals involved in discussions about possible alternative land management scenarios understand how these concepts, when applied in a particular area, will play out over time. Generally we have found that there are two separate sets of issues that need to be explained in this context: first, issues surrounding growth and yield estimates within the stand, and second, issues relating to shifting patterns of management activity at the landscape level. Both strategic overview and spatial pattern visualizations were created to address the landscape-level issues of temporal dynamics, leaving the communication of growth and yield to more place-specific exemplars. While we have found that this combination of visualizations is quite helpful in communicating these complexities, it is usually essential that the experts/presenters offer additional explanations and interpretations as well as answer questions that invariably arise from showing environmental visualizations, regardless of the audience. This engagement of the audience in a knowledge-seeking (and it is to be hoped learning) process may be one of the more valuable characteristics of environmental visualization. However, dependency on selected realistic images, emphasis on more visible aspects of forest management scenarios, and reliance on the presenter's narrative (with all its potential biases), may pose significant threats to the validity of the presentation if not carefully controlled. Luymes (2001) has for example pointed out the risk of sophisticated and authoritative visualizations convincing lay-people to believe models or predictions which may not be scientifically valid.

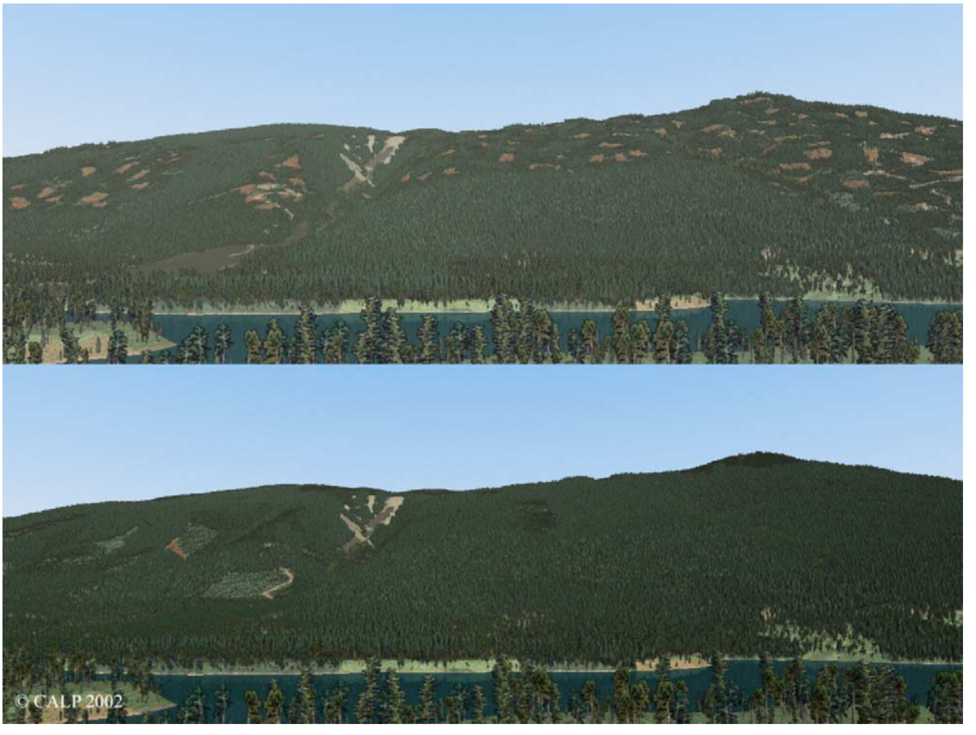

Fig. 5. Visualizations of alternative forest management scenarios depicting differences in the spacing, size, and location of clearcuts.

Lastly, and most importantly, temporal visualization sequences were created to represent alternative forest management scenarios (e.g. Sheppard and Meitner, 2005; Seely et al., 2004). Here multiple visualizations from exactly the same camera location were created for each scenario at identical time steps, so that these visual representations could be viewed side-by-side to allow for direct comparison of the visual effects of one management scenario versus another, as seen in Fig. 5.

This side-by-side comparison allows participants to quickly get a general sense of the type, frequency, and the location of management activities proposed in a given management scenario. It also allows for the overall impacts on the aesthetic aspects of the viewshed to be estimated and in general, facilitates the judgment of overall visual quality by the observer. In addition, these visualizations almost always appear to increase the participants' level of interest in the discussions and tend to hold their attention. Achieving this level of engagement is often very important to the overall success of a given land management decision-making process, as such processes are often rather time intensive, dry and information-heavy. Because visualizations present information in a way which people are highly adapted to understand quickly, a great deal of information can be conveyed while minimizing the stress or time demands on participants.

4. Conclusions

New data-driven and increasingly automated visualizations of possible forest management futures are now becoming feasible, and offer some advantages in conveying these complex spatio-temporal alternatives. They appear to be useful in forging common ground for interdisciplinary teams and exposing issues which might otherwise be missed. Ultimately the primary goal of presenting these visualizations to people is to solicit meaningful feedback and in this capacity, a picture is certainly worth one thousand words. That is to say, each time we have shown these visualizations to a group of lay public or experts alike, they have always sparked a great deal of discussion about the forest management scenarios and, just as importantly, a thoughtful critique of the relevance, accuracy and utility of the visualizations themselves and the underlying models. It seems that simply creating a picture of a proposed management alternative causes people to question and think about these proposals in ways that they might typically not do otherwise. Inherently this may prove to be one of the single most important aspects of this work. The worst outcome of any planning process would be to bore the participants to tears, not solicit meaningful feedback on the proposals, and ultimately implement those proposals only to find at that stage that there is in fact a great deal of opposition. This situation fails to address concerns when their solutions would be most easily and cost-effectively implemented. Environmental visualizations offer the potential to get people interested in these planning processes and if applied appropriately, in conjunction with a great deal of supporting information, to allow for the refinement of improved management alternatives that are both sensitive to the concerns of the society at large and the agencies or companies responsible for their implementation.

It must be recognized that environmental visualizations alone cannot achieve good decision-making, and that significant risks may be incurred from inappropriate use of visualizations. The challenge for research, reflected in the goals for continuing research into visualization at CALP, is to test, measure, and verify the benefits and risks of using these powerful tools in decision support contexts, and ultimately build a stronger basis for ethical codes of conduct for their appropriate use (Sheppard, 2001). However, we do believe that environmental visualizations offer considerable potential if applied (together with other tools) to interdisciplinary planning and decision support processes in an ethical and meaningful way.

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