Visualizing spatial forestry data: knowledge management in the 3rd dimension

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Abstract:

In recent years, we have seen a great deal of expansion in our knowledge of forest ecosystems and the underlying management dimensions that support decision-making in this context. Forestry, much like other natural resource management disciplines, is faced with the challenge of integrating information from many different perspectives often with limited understanding of the basic principles of the multitude of specialized fields from which they are generated. This problem is only exacerbated when discussing management options with both statutory decision makers (often from non resource management backgrounds) as well as the general public. To aid in mitigating these difficulties of communication, methods of visualizing spatial and temporal forestry data will be discussed and possible standardizations will be presented. Ultimately, the goal of this work is to expand our ability to explore, critique, and understand forestry data while dealing with issues of complexity and familiarity with the concepts.

Members of the Collaborative for Advanced Landscape Planning (CALP) at UBC have recently been involved in a number of studies to explore the use and potential of environmental visualization technology in interdisciplinary forest management planning and decision support. These studies have included development of a number of advances aimed at increasing the speed, automation and accuracy of environmental visualizations, to assist both experts and the lay public alike in understanding the important but complex issues involved in sustainable forest management. CALP is an informal group of researchers at the University of British Columbia specializing in landscape visualization and environmental perception, with specific emphasis given to the application of these bodies of research to the development of public land management processes and sustainable landscapes. 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.

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, et al., 1976) 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 & 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 (eg. 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, potentially soliciting 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; Daniel, 1992; Orland, 1993). 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 & Karadaglis, 1997), including applications designed specifically for support of forest health planning and management (e.g., Baker & Rabin, 1988; Daniel et al., 1990; Lynch & 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 (eg. Orland and Uusitalo, 2001).

This paper specifically addresses point number three above by investigating how and why we might derive visual representations of forest data that are capable of increasing our understanding of forest management issues. If we truly want to engage people in forest land use planning and forest practice decision processes we must find better methods for them to access scientific information. In a democracy, it is essential that all stakeholders be involved in these processes. However, democracy only serves society well when all contributing to decision processes are well informed. The problem is that forests and forestry are complex. In fact, in the complex systems literature, the most common example given to explain the concept of complexity is an ecosystem. In forest management this biophysical complexity is accompanied by social complexity, which generally frames our discussions of the former. For example, what are our goals, how do we conceptualize and represent our values as they determine our visions of desired future forest conditions, and how do we monitor our effectiveness at achieving these desired outcomes? Social complexity is also characterized by continuing change in our values, and by the process of selecting individual values from the myriad of values that the forest has to offer.

Both of these complexity sets, the social and physical, give rise to significant challenges when we attempt to discuss forest management problems. Complex systems are necessarily conceptualized in many different ways. Our lens of experience colors our internalizations of complex external perceptions. For example, when gathering disciplinary experts to address ecosystem management problems, each brings a predefined set of terminology and mental models of phenomenon that are unlikely to be universally held. Often this results in debates of semantics and limits the usefulness of highly domain specific knowledge as we are unable to deliver these kernels of wisdom in a form that can be easily digested. Complex systems are also characterized by high degrees of interconnectivity & low decomposability (Casti, 1994). To address complex problems, complex models are needed and the creation of these models depends on our ability to integrate the multiplicity of relevant subcomponents. This reinforces the need to address the problems of communication just described. However, the fact that all of these subsystems are interacting also gives rise to another component of complex systems, the fact that small perturbations of input conditions often result in large changes in outputs. For that reason it is imperative that we develop methods to evaluate the validity of these outputs and make every effort to communicate those results, thereby subjecting them to increased scrutiny and peer review.

There are two additional aspects of complex systems that shed light on issues of communicating forest management problems. By their very nature complex systems are quite large when compared to their atomistic components and second, our conceptualization of a given complex system is scale dependant (i.e. complexity varies with depth of examination). In other words, if our level of analysis is a tree, we view forests quite differently when compared to representing forests as stands, which in turn is very different from looking at molecular activity within the tree. We can restate this as the tenet that complex systems are always nested hierarchies of complex systems. These characteristics of complex systems give rise to issues of reference. How do we shift from one level of analysis to another and in turn how do we make these multi-scale models relevant to the human condition? Ultimately, our success or failure in communicating these issues by means that relate to people’s daily lives determines the salience of these representations to the formulation of societal goals and therefore elucidates the relationship between social and physical complexity as related to forest management.

Visualization holds much promise in addressing a number of these problems in communicating complexity as well as promoting a deeper understanding of complex models of forest systems. As a tool for furthering our understanding of complex scientific information, visualization has proven extremely useful. This is often accomplished by a variety of means given the numerous disciplines employing these methods but in light of the issues discussed above there are a few aspects of these technologies that deserve mention. First and foremost is the ability of scientific visualization to make explicit our mental models. Through the very process of creating a visual representation one is forced to unambiguously specify many details of how we understand the underlying data used to drive the simulation. This addresses the concern raised by multiple conceptualizations of a single aspect of a system and capitalizes on the fact that visual mediums are unaffected by linguistic ambiguity. Therefore you might think of visualizations as a type of global translation. Additionally, these visual depictions allow the creator (or scientists creating the underlying data) to evaluate the face validity of these outcomes and to iteratively refine the models that drive them.

Visualization is also a very powerful communications tool. It exploits our natural abilities to intuitively grasp visual information. A majority of all information processed by human beings is visual in nature and as a result of this reliance on vision we have evolved a visual perceptual system that can quickly process immense amounts of data with very little cognitive effort on the part of the perceiver. Visualization also extends our perceptual system by allowing data that might be non-visible in nature to be presented. We can also represent large and small scale data, not commonly available to us, in ways that make them relevant to the human condition. For example, imagine viewing a time-lapse movie of a flower blooming. By compressing the temporal scale we are able to witness aspects of the world around us in ways not possible without the aid of technology and subsequently benefit from the insights that might be had by the experience. This temporal compression is extremely relevant in the context of forestry. We are often faced with making decisions today that will impact future generations and by bringing the future to life through scientific visualization we can allow an individual to more easily put themselves in the shoes of their children's children. This provides a far richer environment by which individuals might evaluate the future they would like to pass on to future generations. The last aspect of visualization in the context of communication is translation. While we have already discussed how disciplinary experts might be aided by this technology it is equally important to think of this aspect of visualizations from the perspective of simplifying complex scientific information for consumption by non-academics. However it should not be assumed that this is a one way street as these technologies are equally able to represent the mental models of stakeholders there by allowing the simplification of social complexity to flow in the other direction.

In discussing the role of visualization in both understanding and communication it is important to realize that the ways in which we utilize this technology and the benefits that we might derive are limited by the context of their application. An expert in watershed hydrology will not necessarily benefit from the same visualizations as a forest manager would and children might have very different expectations of the visual representations of forests as compared to a representative from an ENGO. This can be conceptualized as variability in our collective conceptualizations of issues and our associated levels of comfort with various representations of those conceptualizations. Table 1 lays out a simple working model of this as a means to explore the differing roles that visualization might play in different contexts.

Scientists/Academics	Disciplinary experts
	Generalists
Stakeholders	Practitioners
	Decision makers
	Interested/motivated public
General Public	Disinterested public
	Children and young adults

Table 1: A generalization of intended audiences for a particular visualization

We will not discuss in detail all of these cases made explicit by this figure but rather will chose a few of the contexts to illustrate the idea. It is not our intension to exhaustively list all possible uses of visualizations given a context but to give examples that shed light on the interplay of the goals for a given visualization and their intended audience. Since we have already drawn on examples of the disciplinary expert, we will begin with the generalist. In this case the goals for visualization might be to aid in the integration of information from multiple disciplines. This might be used in the context of investigating interactions among subcomponents of the model or alternatively might be used to investigate those same interactions as representations of social values that might be traded off. The generalist might also be quite interested in how to use these images to communicate to non-scientists.

In the case of the practitioner, for example a professional forester, it is likely that they would also be interested in the aforementioned uses, but they might also desire a greater degree of relevance to operational management issues. For example, the ability to use visual representations of management alternative to explore possible outcomes in the context of social expectations would likely be of interest. Additionally, visualizing operational plans to both explain these plans to fallers as well as to elicit feedback from ground staff regarding operating conditions that impact things such as worker safety might also be desirable. This class of user would also likely use this technology to increase the effectiveness of their interactions with scientists and stakeholders.

At the other end of the spectrum are children. In this case visualization holds a great deal of promise to have very large effects in building a new generation of well informed citizens to participate in shaping the future of our world. First, visualization capitalizes on existing technological affinities so common in the younger generation. By creating compelling visual representations of science we might very well spark some interest in an individual to pursue that career path. Second, we might hope to foster a sense of curiosity about their relationship to the natural world. Lastly it might also be possible to increase the meaning and relevance of environmental management issues.

In each of these examples the details of what would constitute an effective representation of exactly the same underlying data might differ greatly. Imagine a representation where trees and shrubs are drawn as color coded geometric cylinders to represent fire hazard categories. This might be a very effective representation for an expert in this area to assess overall patterns of their model output but would certainly be less than desirable for explaining the causal mechanisms that drive this classification to the lay public. In the latter case, a series of visualizations depicting prototypical cases of fuel loading configurations might be far more effective. This example illustrates the point that, in order to use visualization most effectively, we must explore many alternate representations and evaluate our choices of depiction based on the goals we set for either facilitating communication or understanding in a given context. Therefore, it becomes imperative that we clearly articulate those goals and define the target audience so we can critically assess our likely effectiveness in meeting our objectives.

However, several important factors specific to the human capacity to accurately and wholly assimilate information remain fairly constant, no matter whom the audience is. As humans we can accurately evaluate one quantity relative to another similar quantity but are almost completely inept at gauging the absolute value or size of an unreferenced quantity. We are able to estimate relative proportions far better than absolute quantities and can understand averages and norms but are useless at computing such values by means of accurate sampling and on the fly calculation in our heads. We struggle to accurately measure duration (Ariely, Kahneman, & Lowenstein, 2000) and, with the exception of a handful of trained professionals, are incapable of accurately locating and orientating complex spatial arrangements in our minds eye. Automatically draping these arrays over a cognitively generated three dimensional landscape creates even larger problems. We are capable of detecting subtle changes when one situation is evaluated immediately after another but are incapable of detecting this change when a time lapse or mask is applied between the two situations (Rensink, 2000). This makes us very weak at detecting variations in acceleration and deceleration of trends. According to research on fingers of instantiation (FINSTS), humans are capable of manipulating no more than six variables at a time (Fisher & Dill, 2000; Rensink, 2000). When doing this, we have a tendency to manipulate a single variable whilst holding all others constant. For this reason, we are highly incapable of rationally optimizing a series of predictors such as a computer might do in a simple linear regression model. Research in both education admissions and commerce has shown that a simple linear regression will outperform a group of professional evaluators almost every time. In fact when evaluators are provided with the regression scores ahead of time, the computer model is still able to outperform their predictive capacity in almost all cases (O'Shaughnessy, 1996).

Once we understand (and are willing to accept) where our judgment or assimilation capacities are weak, we can set out ways to minimize error. More specifically, it is possible to use visualization to help to alleviate some of these problems. To begin with, visualizations contain large numbers of spatial and size cues which we subconsciously use as comparators when evaluating the dimensions of unknown quantities being presented. Conversion of tables or lists of variables into spatially arranged visualizations allow us to maximize our ability to use relative proportion estimation to understand quantities. At the same time, the subconscious cues mentioned before help to anchor these relative proportions allowing us to more easily make the necessary conversions over to absolute values. For example, visualizing a harvest area relative to a football field inserted to scale in the same image is far easier to comprehend than reporting the size of the cut to be an abstract value such as 0.76 hectares. Similarly, visualizing a distribution of patch sizes and shapes on a landscape is far easier to relate to than reporting the mean and standard deviation of the areas together with the distribution parameters for the ratio of edge to interior.

Temporal variations are perhaps our weakest point. This is totally understandable because from an evolutionary perspective, we as humans have only ever had to deal with the here and now. The escalation of the scale of human impact over the last 200 years has forced us to start to take temporal scale into effect. This is clearly not something we have evolved to do and in many cases we still respond to situations with a totally “here and now” attitude, evaluating temporally extended experiences as an average between highpoint and endpoint (Ariely et al., 2000). Visualization can aid this weakness by condensing time in such a way that we are better able to comprehend subtle shifts. In simple univariate cases, graphing temporal variation as a series of points in X and Y is highly effective but because of the limitations we have in co-processing bi or multivariate FINSTS, assimilating temporal interactions of variables is almost impossible and requires great effort. Even when this effort is taken, we often end up with nothing more than a “gut feel” for what is really going on. By condensing time and depicting these variables using visual objects referenced in a perspective view, we minimize the effects of “change blindness” (Rensink, 2000) and are able to harness our incredibly powerful visual ability to comprehend complex interactions. As an example, understanding the simple relationship between deforestation and erosion as it relates to steepness of slope is difficult when presented as a series of graphs and distributions. In a visualization of this interaction, steepness of slope is subconsciously assimilated as is the difference between forested and harvested areas, leaving the viewer free to evaluate the single remaining variable, relative size of erosion effect. This too is simplified in that the absolute values shown on the graphs and plots have been replaced by scaled depictions of these effects which can be evaluated relative to each other prior to conversion of these relative sizes into actual finite quantities.

Visualizations can also help us to more accurately detect fundamental errors or errors of omission in prediction models (Meitner et al., in press). As mentioned earlier, humans are very weak when it comes to mental linear regression. We are quite capable of rationally arguing and dissecting how any two variables might interact but struggle to rebuild the whole picture. Visualization not only allows us to spatially view individual variables or data sets, but allows us to view the aggregated output of several combined variables. Let us once again take a look at the simple erosion example discussed earlier. Our model predicts that erosion is positively correlated to both level of harvest and steepness of slope. By converting our model into a data driven visualization, we can instantly pick out places where unknown data holes exist. We can also immediately see that our model is not complete. Erosion patterns appear far to uniform across the entire site and we are forced to reconsider the possible differences in hydraulic action between cases where sheet flow and channel flow occur. This might lead to a second iteration and eventual refinement of the model. Had we not visualized this, electing rather to retain our data as graphed averages, this omission would never have come to light. In this way visualization is central to the conversion of information to knowledge through the nearly effortless incites that this medium facilitates.

The list of forestry related variables that can be visualized so as to improve comprehensibility is just about as limitless as the number of GIS coverages and thematic variables already in existence today. A somewhat glib general rule of thumb would be “if you can map it, visualizing it can only help to improve comprehension”. A short list of examples include analysis of existing site conditions such as topography, hydrology, pedology, nutrient levels, floral species distribution, faunal species distribution for feeding, breeding, nesting and resting and current and historical human use. Representing temporal sequencing or bivariate or multivariate interactions of any of the above is where visualization starts to come into its own right.

Conclusions:

Superficially, the creation of relevant visualizations appears to be a fairly straight forward undertaking as evidenced by the plethora of tools for creating purely data-driven visualizations of future environmental states. However, when examined more closely, using visualization in the context of understanding and communication gives rise to several significant questions. How do we present visual and non-visual information on an equal basis? What are the strengths and weakness of different approaches to visual representations for generating a deeper understanding of the information represented? What is the effectiveness of different visualization systems at engaging different audiences? What are the ethical implications of using these powerful communication tools in a decision making context? These are just a few of the significant concerns raised by the increasing use of ever more realistic visual depictions of future conditions. We would agree that they need to be addressed but would also argue that the pressure of environmental concerns prevents us from awaiting complete answers to these questions. It is imperative that these technologies be applied as a component of the land management decision-making process. Therefore we should proceed with caution while continuing to develop our ability to represent unbiased land management information through visual means.

Ultimately the goal of CALP’s more technical work is to apply it in investigating the potential of these technologies to disseminate information to the public and to act as vehicles for increasingly interactive 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. This work moves us one step closer to realizing this goal and while we continue to strive to improve our technical ability to translate forest data into images to communicate future forest scenarios to the general public we realize that it is equally important to ask question about what role these visualizations play in the larger societal context. Our hope is that these advances in translating numeric representations of future forest conditions into more salient visual representations will help to engage the public in the discourse around natural resources decision making and ultimately lead to a more inclusive, representative and balanced participation in this process.

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