GEOVISUALIZATION OF FOREST DYNAMICS:

HEMLOCK WOOLLY ADELGID DAMAGE

IN GREAT SMOKY MOUNTAINS NATIONAL PARK

by

HUNTER ALLEN

(Under the Direction of Marguerite Madden)

ABSTRACT

Geovisualization techniques were used to describe and assess vegetation changes from the invasive exotic, hemlock woolly adelgid (HWA, *Adelges tsugae* Annand), among eastern hemlock (*Tsuga canadensis* L.) forest communities in Great Smoky Mountains National Park. Satellite imagery, aerial images, GIS-vector databases, digital elevation models and GPS field data were used to create photorealistic renderings 3D, multi-scale perspective views and animations. Plot-level visualizations included 3D tree models and field data to reconstruct forest structure. Existing vegetation databases were used for depicting pre-infestation conditions and derive forest structure changes at the landscape and stand-levels. Recent USDA National Aerial Imaging Program (NAIP) imagery provided post-invasion information to update existing vegetation databases and describe dieback patterns at the landscape scale. Targeting visual acuity of human cognition, results of this work offer innovative methods for assessing and portraying to various audiences the implications of losing a foundation species in the southern Appalachian forests.

INDEX WORDS: eastern hemlock, hemlock woolly adelgid, geovirtual environments (GeoVEs), geovisualization (GeoVis), photorealism, forest dynamics

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HUNTER ALLEN

BFA, University of Georgia, 2001

BS, University of Georgia, 2006

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Major Professor: Marguerite Madden

Committee: Thomas R. Jordan
Albert Parker

Electronic Version Approved:

Maureen Grasso
Dean of the Graduate School
The University of Georgia
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DEDICATION

I owe all this to my Mom and Dad, whom without I would not have had a chance to experience the good work, the fun, the beauty and the agony. This work is a small testament to what they have taught me and a personal effort to continue to practice their advice: always learn, be aware and accept the challenges of a forever changing world.

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CHAPTER I

INTRODUCTION

Geographic information systems (GIS) can encompass all phases of geospatial data gathering, processing, analyzing and communication within a computer-based environment. Geovisualization (referred to often as GeoVis) techniques, specifically, are used to communicate information about geospatial data via exploration or presentation and involve the display of 2D, 3D and 4D (time) representations of those data. Many traditional cartographic principles underlie these techniques, yet with geovisualization many more opportunities exist that allow for enhanced user interaction and intensified representation of GIS domain objects (themes), images and terrain data. Geovisualization techniques can even include the engagement of haptic (touch) and auditory senses.

Geovisualization, according to MacEachren et al. (2001), involves the integration of many different disciplines and technologies including elements of scientific computing visualization (ViSC), cartography, image analysis, information visualization, GIS and exploratory data analysis (EDA). This coalescing of disciplines and approaches provides a theoretical, methodological and tool-based system of visual exploration, analysis, synthesis and presentation of data that has geospatial qualities and referencing (MacEachren et al. 2001). With the continued integration of gaming graphics and GIS, photorealistic geovisualization techniques increasingly narrow the gap between what is considered real-world experience and that of virtual environments used for internalized problem solving (Döllner 2005). This relationship has fostered some of the current virtual systems used in landscape and natural resources visualizations, which utilize individual plant models, vegetation models, and landscape models.

Humans are visual creatures obtaining 80 percent of the information about our environment from our visual senses (Lange 2005, citing Bruce et al. 1996). We learn by moving and exploring our environment, and our eyes are capable of stereo vision allowing 3D information to be obtained. Thus, our brains are naturally predisposed to this type of visual input. It makes sense that we should gain understanding and learn from an environment that simulates these qualities that we usually experience and enjoy. Representations of the real environment in a computer-based platform that emulate real world experiences in 3D as they change over time offer a better interface compared to flat 2D abstracted maps and figures.

Landscape visualization is gaining much attention in planning and forestry practices and visualization techniques are recognized by many as useful tools for conveying complex management scenarios to diverse audiences (Appleton et al. 2003, Dunbar 2004, Bishop and Lange 2005, Cavens 2005, Song et al. 2006, Gardiner 2007). The geovisualization tools associated with landscape visualization, including advanced graphic media and gaming engines, allow producers and users to experience geospatial data in new ways. The unique combination of image and object geometry found in graphic media environments within the geodetic spatial framework of GIS (i.e. geovirtual environments) has provided a viable way to represent geospatially accurate virtual environments with realistic colors, textures and forms.

Geospatial data, including satellite images and air photos, are typically acquired from a vertical viewpoint that is essentially foreign to most of us who experience our environment from a ground view. Even image interpreters struggle with the specialized orientation needed when working with landscape data presented in a bird's eye orthogonal view compared to the perspective views from familiar positions on the ground or oblique vistas. By generating perspective views that emulate recognizable positions of sight and using representations of thematic domains in datasets that are similar to objects people experience daily, the context and the patterns of what we experience in the real world can more readily be associated with representations of geospatial data. The types of visualizations presented in this work offer a more intuitive way to experience cartographic products that are traditionally a very abstract and flat perspective of data. Also, today we have rich sources of landscape data originating from digital imagery and existing GIS databases. Computer technology also is available to handle these large amounts of data with graphic media and interfaces that can represent these voluminous data sets using high resolution displays. A challenge now is how to best utilize these new tools and how to refine the datasets to make the most efficient and effective use of geovisualization technology.

In order to create effective visualizations, choices must be made up front about the needs of a visualization project. This will facilitate the integration of various data and help expedite the visualization design to meet predetermined goals. Not all patterns and themes are immediately apparent in any one data set, nor can they all be represented with a single data model or representation technique. Although not all data should be represented with photorealistic techniques, most spatial data can be adequately represented with objects that construe the real world, with color and texture that are based on reality, i.e., the environment that most people experience in their daily lives.

These issues of cognition, in addition to the technical aspects of digital data integration and use of complex software that constitute geovisualization, are of major interest to researchers as they determine the most effective and appropriate ways to utilize geovisualization techniques to create geovirtual environments. Currently, much research with photorealistic landscape visualization techniques has pointed out that it is not so much a matter of the usefulness of these techniques that is of concern (most agree the techniques are useful when used properly), as it is a matter of maintaining high levels of transparency throughout the process (Sheppard 2001, Appleton 2003 and 2009, Cavens 2005, Bishop and Lange 2005). This includes being clear to users about the goals of the visualizations, the data used and the methods or approach of the design when producing and distributing realistic virtual environments of environmental data.

A powerful use of photorealistic, 3D perspective views of landscapes is the portrayal of the projected results of land use operations, management plans, and proposed development. Much work done in the field of visualization has addressed issues of communication, understanding, data accessibility, realism, and the idiosyncratic needs of professional versus lay audiences when utilizing photorealistic landscape visualization to describe various situations in a landscape (Lange 2001, Sheppard 2005, Lewis and Sheppard 2006, Song et al. 2006,). In many circumstances, audiences include trained and untrained individuals of various skill levels and familiarity with geospatial techniques. The work in this thesis abides by existing methods of incorporating realism into visualizing geospatial landscape data, yet it also offers new approaches of producing landscape visualizations and results which meet the needs of both scientist and lay persons. Specifically, geovisualization techniques are employed to better understand some of the implications of extensive dieback of eastern hemlock (*Tsuga canadensis* L.) in the southeastern US due to the recent invasion of the exotic hemlock woolly adelgid (HWA, *Adelges tsugae* Annand) in the southern Appalachian Mountains.

Methods are needed to provide ways to help varied users understand geospatial data sets depicting the impacts of hemlock dieback in this diverse environment. These types of geovisualizations are needed to help elicit awareness such that people will continue to invest time, energy and financial donations to mitigate the elimination of this key forest component. Although HWA dieback deserves attention and is causing significant ecological disturbance by removing a critical shade tree and exposing streams and forest floors to increased light, wind and temperature, there are many other species within communities and ecosystems that are under constant perturbation and disturbance from pathogens, human activities and climate change. The methods used in this study also can be applied to a myriad of circumstances that require landscape analysis for managing threatened natural resources.

Objectives

In this study, the creation of multi-scale, spatially explicit 3D renderings and animations utilizing photorealistic geovisualization techniques offered further understanding of potential biological and physical changes in forest community structure within the biologically diverse Great Smoky Mountains National Park (GRSM) due to the invasion of the hemlock woolly adelgid (HWA*)*. The geovisualization results are based on explicit geospatial data that has specific coordinate geometry and, in the case of digital imagery, explicitly georeferenced spectral characteristics. Thus these renderings offer a visual assessment of temporal changes in forest structure at georeferenced locations using the unique capabilities of photorealistic geovisualization to make specific domains of integrated geospatial datasets visually accessible to diverse users.

The 3D-perspective renderings and animations produced here create an enhanced interface to geospatial data that brings insight and understanding to both scientist and lay persons who have a vested interest in the ecological impact of HWA in the southern Appalachian Mountain region of the southeastern U.S. Such techniques can be further developed and streamlined to aid in visual analyses of various spatial data sets from multiple scales and offer access to information on pressing scientific issues to anyone involved with or concerned about public lands. These methods directly address issues of geospatial data integration, representation and cognitive utility and offer contributions to both agendas outlined by the (ICA) and the University Consortium for Geographic Science (UCGIS) (MacEachren et al. 1999, Buckley et al. 2005).

When making decisions about HWA control strategies to mitigate this particular infestation, park managers require continued consultation with various interest groups and the general public. Thus, there is a need for the public to review proposed actions and provide necessary comments and amendments. Interested groups of people include, but are not limited to, conservation groups, city and county officials, congressional representatives, and tourism officials, all of whom will be solicited for public input on the parks management alternatives for HWA (Soehn et al. 2005). Renderings from geovisualization techniques used in this study are well suited for education and outreach to this broad audience. This study aims to demonstrate the use of geovisualization techniques to assist land managers of GRSM in responding to the ecological and aesthetically devastating infestation of HWA and the broad scale dieback of hemlock throughout the park. Specific objectives include the following:

1) Develop and build a library of 3D and 2D vegetation models (tree species especially) that are colloquial to the GRSM. This library will be tailored to the southern Appalachians and be available for other regional visualization projects.
2) Establish a methodology that demonstrates efficient use of available geovisualization software packages to integrate disparate geospatial data sets such as terrain data, images, GIS vector data and field-based measurements, and to establish a link between specific

domains (i.e. themes) and appropriate visualization elements or components. Special attention will be paid to factors of immersion and level of detail in virtual environments.

3) Provide visualization results of HWA dieback in GRSM that foster a conceptual understanding of landscape disturbance at multiple spatial scales. The results are expected to generally allow diverse users to access complex geospatial data and foster greater understanding of interrelated landscape patterns and processes.
4) Provide immersive, realistic representations of geospatial data (i.e. 3D perspective views and animations) that engage and stimulate interests in complex ecological changes that occur at local, stand and landscape scales. These types of interesting communication interfaces can be applied by park managers to educate and engage the public about issues facing conservation areas and participate in research, management and policy decisions.

CHAPTER II

LITERATURE REVIEW

Hemlock and the Hemlock Woolly Adelgid

In the last ten years, the southern Appalachian Mountain region, including Great Smoky Mountains National Park (GRSM), has experienced a significant disturbance to the stability of forest ecosystems dominated by the eastern hemlock, due to the invasion of the exotic insect, hemlock woolly adelgid (HWA). Native to Asia, HWA was first reported in the eastern United States in 1951 near Richmond, Virginia, and by 2005, it was established in portions of 16 states from Maine to Georgia (McClure et al. 2001, Kooch et al. 2006). The spread of HWA

a b

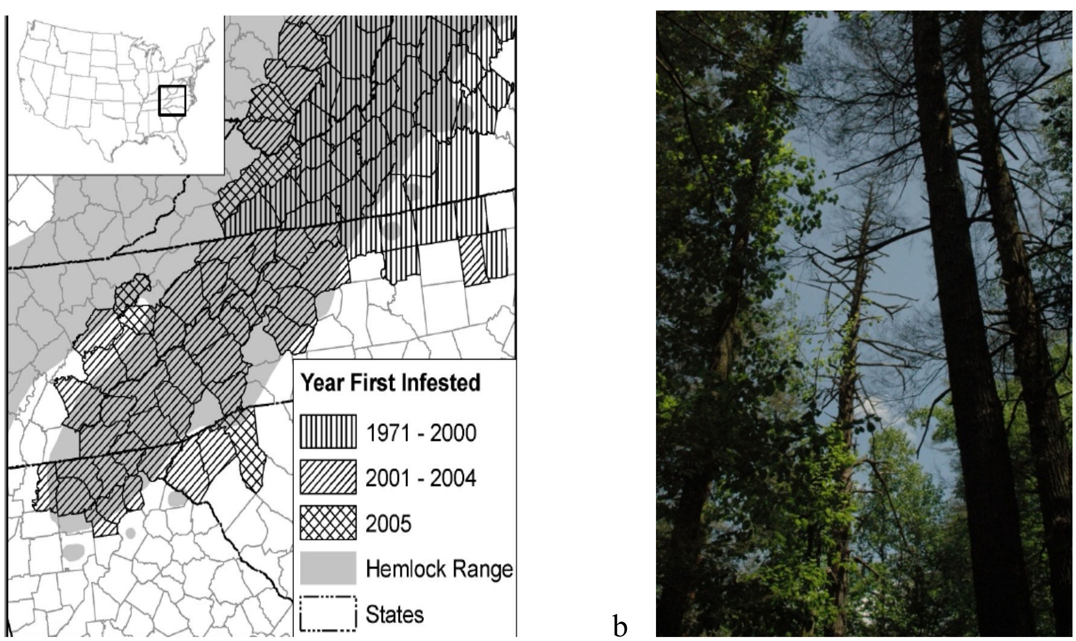
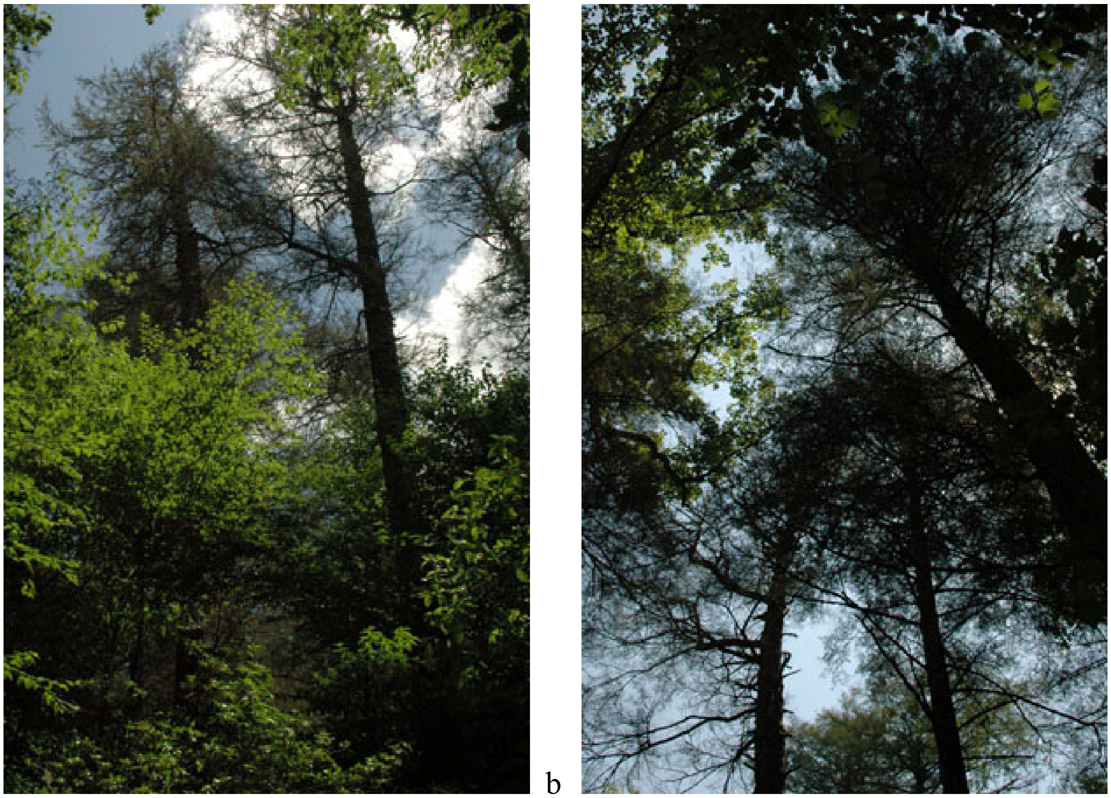


Figure 2.1 (a) Spatio-temporal pattern of HWA spread in the southeastern U.S. (from Kooch et al. 2006) (b) Photo from the Cataloochee Valley on the North Carolina side of the Great Smoky Mountains National Park revealing the dieback in a stand of hemlock.

throughout the eastern U.S., and most recently in the southern Appalachian Mountains, has many researchers and land managers racing for information and searching for methods to help control and mitigate the devastating effects of the hemlock decline (Fig 2.1). This is especially critical in GRSM where old growth hemlocks reach ages of 300years or more. Hemlock woolly adelgid, though, affects hemlocks of all ages and trees can be killed in as few as 3-5 years (Bonneau et al. 1999) (Fig 2.1).

The eastern hemlock holds a unique position in forest communities. Capable of growing in low light conditions as an understory species, this tree can often grow in diverse environments including dryer sites that do not especially suit its preference for moist habitats. Later, when hemlocks grow in size and number to play a dominant role in the community, the shade created by the evergreen hemlocks with low growing branches can create moist microclimates that are critical as habitat for many endangered and endemic plant and animal species (Ford et al. 2007). Hemlock, therefore, plays a vital role within forest and riparian ecosystems by providing habitat for wildlife, mediating stream temperatures for fish and aquatic insects, and offering a stabilizing effect on hydrologic budgets (Ford et al. 2007). Hemlock forest communities also tend to have high biomass and complex chemical pathways of nutrient cycling which substantially affect ecosystem processes (Ellison et al. 2005). Once hemlock populations are invaded by HWA and decimated, the legacy of these trees and their potential to maintain viable moist habitats in the forest is lost. The resulting removal, observed to be 100 percent in some areas, of a major evergreen forest canopy species increases light penetration resulting in higher surface temperatures and loss of moist conditions (Fig 2.2).

Along the east coast, the hemlock's role in stabilizing microclimates has been severely affected by HWA invasion. Well documented changes in ecosystem processes have been observed in the northeastern U.S. where hemlock decline has advanced for several years resulting in major changes in forest stand structure (Stadler et al. 2005).



a b

Figure 2.2 Ground photographs clearly show current conditions of large dominant hemlock trees in the park. Various levels of dieback can be distinguished from heavy (a) and moderate (b) damage. Also discernable is the resulting differences in light penetration levels which affect exposed vegetation in the sub-canopy.

In Connecticut, for example, researchers have observed that the loss of hemlock leads to much more homogenized landscapes where species such as black birch (*Betula lenta* L.) have established prolifically in areas of hemlock dieback. Tree species noted by high annual seed production and close association with hemlock, such as maple (*Acer* spp.) and oak (*Quercus* spp.) are expected to be seen where hemlock once stood (Orwig et al. 2002). Most hemlock stands in the northeastern U.S. have been replaced by broadleaf deciduous species, and this loss of evergreen transpiration function and change in leaf litter composition will have major effects on soil moisture levels and nutrient cycling (Stadler et al. 2005). In the southeastern Appalachians where rhododendron is absent, it is expected that yellow poplar (*Liriodendron tulipifera*) will be a major replacement species (Ellison et al. 2005).

Hemlock Woolly Adelgid in Great Smoky Mountains National Park

According to the U.S. National Park Service (NPS) draft environmental assessment for HWA in GRSM compiled by Soehn et al. (2005), HWA entered the park in 2002 and populations in the park have become more widespread and pose an "imminent threat to park resources". In response, park managers have expanded treatment efforts including the application of insecticidal soaps, oils, and biological control agents in an attempt to prevent complete devastation of hemlock. With a commitment to protect hemlock forests in GRSM, NPS has solicited input from the public and interested agencies concerning treatment alternatives. They are particularly interested in projecting potential outcomes of HWA management options in the park so that optimal and most appropriate actions can be taken (Soehn et al. 2005). In other words, the use of insecticides and biological controls in a national park of world-wide fame for its biodiversity must be prudent and carefully considered.

Hemlocks also represent an important component of identified cultural landscapes. This includes the long legacy of land use in the park that reaches back 12,000 years and incorporates more than 300 archeological sites. Before the residential and agricultural buildings of the park were constructed by Europeans, the Cherokee Indians occupied the land for hundreds of years. The NPS Cultural Landscape Inventory (CLI) has 42 landscapes in the park that are maintained in a database and are considered to be historically significant (Soehn et al. 2005). Visitor experiences will be affected by hemlock dieback since hemlocks are "aesthetically important" for park visitors throughout the year and some sections of trails in the park contain old growth hemlock stands that provide unique hiking experiences. Today, visitors to the park are shocked by vistas that encompass large areas of dead and dying hemlock, thus diminishing their wilderness experience and raising doubts about the success of the NPS to preserve this valuable national resource. The primary responsibility of the park managers is to fulfill the provisions which state the fundamental purpose of the park is "to conserve the scenery and the natural and historic objects and the wild life therein" (Soehn et al 2005).

Part of the NPS Natural Resources Management Guidelines mentioned in the draft environmental assessment state that control measures for HWA in GRSM should include resource education through public programs for children and adults regarding HWA and its consequences (Soehn et al.2005). The NPS must undergo procedures that "include open evaluation, impact assessment, alternative approaches, peer review, and the use of interdisciplinary approach" (Soehn et al. 2005). When considering the need for public involvement, one issue that quickly arises is how to communicate various levels of information to an audience of diverse ages and backgrounds. As noted above, one very important aspect of managing the HWA infestations in GRSM is informing scientists, managers and the public about the infestation and mitigation plans.

The Importance of Utilizing Geovisualization Techniques

Recent themes found in the Research Agenda for the International Cartographic Association (ICA) Commission on Visualization and Virtual Environments focused partly on the representation of geospatial information, computational methods, efficiency and the cognitive or usability of geovisualization (MacEachren et al. 2001). Accordingly, the Agenda called for a coordinated approach to geovisualization research, with goals aimed toward integrated work on technological advances leading to more powerful tools that focus on human spatial cognition. Success may be measured by increased potential of visual representations to help enable "thinking, learning, problem solving, and decision making" (MacEachren et al. 2001).

Buckley et al.'s (2005) chapter on geographic visualization, found in *A Research Agenda for Geographic Information Science* by McMasters and Usery (2004) of the University Consortium for Geographic Science (UCGIS), also focused on priorities for geovisualization research. This Agenda describes how geographers and other spatial scientists are "uniquely positioned" to contribute to advancing the theory and methods of geovisualization. Rather than reiterate the themes of the ICA, the UCGIS Agenda continued to build on those of the ICA by addressing needs of collaborative development, not only within geography but within other academic disciplines, the government and private sectors (Buckley et al. 2005). This interdisciplinary approach creates a context of interdependence among various groups and the need for common tool sets and readily available output products such as those offered by the geovisualization techniques presented here.

Among the priorities for research in geovisualization noted by the UCGIS were: 1) ways to gain a better understanding of the differences between users that may determine the effectiveness of visualization tools; 2) the perceptual and cognitive aspects of communication; and 3) best methods for "abstracting from reality" or the correct amount of realism (Buckley et al. 2005). Also emphasized was the importance of geovisualization in facilitating discussions between scientists and the lay public, and how the ability to represent different temporal and spatial scales is central to "solve the disconnect" with visualization and spatial databases due to the limitations of representation (Buckley et al. 2005).

Photorealism for Understanding Geospatial Data

At the most basic level, this study documents a methodology utilizing photorealistic geovisualization techniques to depict and explore the ecological change in hemlock dominated forested landscapes of GRSM. Issues associated with photorealistic visualization techniques include the integration of disparate geospatial datasets and GIS data representation in 2D, 3D, and 4D. Throughout this study, the efficient use of available computational power was critical and cognitive implications of techniques that employ high levels of realism were considered. Although geovisualization is a generic term that applies to data exploration with visualization tools or geovirtual environments (GeoVEs) where complete immersion may even involve other senses such as touch (haptic) and sound, this work is concerned specifically with photorealistic geovisualization pertaining to landscapes. Thus, it includes graphic realism to enhance a viewer's immersion and interactivity with virtual representations of geospatial landscape data, allowing for potentially greater understanding of those data. Issues pertinent to geovisualization and cartographic representation generally apply to these techniques.

There are essentially two ways to communicate and convey information between human individuals: graphic images and language (Peuquet, 2002). Accordingly, graphic images are very powerful since humans have developed a sense of visual acuity and the patterns found in graphic images allow for the formation of an "image schemata". Referring back to a legacy based on Kant's notion of schemata, or the "pure form in which the matter of knowledge is organized", Peuquet states that this image schemata consists of "schematic patterns grounded in and determined by our bodily interactions with, and sensory perceptions of, our environment in space and time" (Peuquet 2002). This relational and spatial scheme allows for high level associations to be made at abstract levels. Image-based knowledge is advantageous over text and tables because it extends meaning beyond what is immediately portrayed or represented, and it is this more comprehensive image view that reveals "emergent properties" of comprehension where unanticipated image patterns may be interpreted by different viewers and provide new meaning (Peuquet, 2002).

Most cartographic representation and maps of spatial data utilize these concepts, yet these images and graphics are often simple, abstract and designed to convey specific themes. As a less targeted and specialized language, graphic images that are photorealistic provide an efficient mode of engaging the "image schemata" and at the same time can communicate geospatial information effectively and accurately. Essentially, most themes explored by traditional cartographic representation can be linked to realistic proxies in a geovisualization environment to take advantage of visual cognitive pathways. Specifically, the issue here is not simply cognition, but the specific cognitive processes associated with incorporating individual thinking with spatial information processing.

Much of the research in scientific computing and visualization in the last decade has been based on the hypotheses that the most successful visual representation methods are those that take the full advantage of human sensory and cognitive systems that are developed for interacting with the real environment, and as such, emphasis has been on realism applied to objects that are visible in the real world (MacEachren et al. 1999). Döllner (2007) suggests that real-time virtual landscapes, which are considered a general form of geovirtual environments, constitute an "essential user interface paradigm for geospatial information". The fundamental limitation here is that of human landscape perception. Only through the individual interpretation of visual stimuli can the information from the landscape be understood by the viewer to be what we call "landscape". This cognitive result depends on factors including education, experience, and observation (contemplation) (Döllner, 2007). Therefore, much research has been conducted on the interpretation of renderings from realistic visualization techniques and the impact these techniques have on users' perception of landscapes (Daniel et al. 2001, Bell 2001, Lange 2001, Sheppard 2005, Appleton 2009).

Insight in to why 'a picture is worth a thousand words' may be that for communicating information, "the picture coincides with the first most basic means of acquiring environmental information…", thus "…the picture is usually quicker and easier for a person to understand" (Peuquet, 2002). A pictorial representation, according to Peuquet, is a powerful medium for human cognition and understanding due to the arrangement of pictorial elements and the "implicitness of the interrelationships" of those elements. This allows an efficient way to manually process the elements of a representation into information and knowledge (Peuquet, 2002). This efficiency of information stored in imagery allows a quick way for viewers to go beyond simple understanding of the cartographer's message and enable viewers to add their own knowledgebase and memory to multiple interpretations of the same image or photorealistic geovisualization.

<u>Cartographic Designs and Data Models for Geovisualization</u>

In addition to the cognitive issues that are associated with photorealism, the arena of technological applications and development in graphic sciences and modeling are significant to this study. Bodum (2004) extends some of the basic cartographic concepts into the science of virtual environments including generalization, visualization, manipulation, perception, and interpretation. Many of these principles are related to representation, the term used for 'building' the virtual environment" (Bodum 2004). Aspects of representation include constructing the data model, performing 3D modeling, and deciding on what to include/exclude to determine level of detail (LoD) and realism in the overall virtual landscape model (Bodum, 2004). A basic understanding of the technological foundation of these techniques is important since they provide the means to effectively communicate in the realm of geovirtual environments (GeoVEs).

Any cartographic design procedure must take into account the data that are to be represented and the choice of the model for representation. The design should be based on the most efficient and effective way to communicate the desired themes or patterns within that data. At the very least we should be constantly investigating ways to escape the 2D "flatland" of traditional map displays and "looking for new immersive ways of experiencing the world (or worlds) to find new and innovative answers to our many questions" (Bodum, 2004 citing Tufte, 1990). The data model, as well, must receive attention since with the use of 3D complex objects in virtual landscapes demands the extension of the traditional flat geometries such as lines, points and planes. Bodum (2004) emphasizes the establishment of a proper data model in a virtual project is critical and should be based on the techniques used and the goals of the final application. In addition, the use of traditional relational databases are not appropriate in many multi-variate and multi-modal systems that must deal with a sufficiently higher level of complexity than that seen with most standard GIS platforms (Bodum, 2004). Object-based and component-based systems are the most efficient when dealing with virtual environments (Lintermann 1999, Bodum 2004, Deussen and Lintermann 2005). Fortunately, many visualization platforms such as Visual Nature Studio by 3D Nature Inc. (VNS) utilize ways of importing data sets into their own configuration to meet the needs of managing virtual system requirements including 3D objects, GIS databases and rendering with high end graphic engines.

The results of this work touch on a few factors MacEachren (1999) referred to as "delineating elements of geospatial virtual environments" or GeoVEs. These factors, (immersion, interactivity, information intensity, and intelligence of display objects) either together or independently, contribute to creating virtual environments that portray what may be experienced in the real world (MacEachren et al. 1999). Two of these four factors, immersion and information intensity, pertain particularly to the photorealistic techniques of this work. Although, immersion, defined as the sensation of being in the environment, is invoked purely through visual means in this project; it may involve other sensory aspects of real world experiences including sound, smell, and tactile (haptic) sensations. The other factor, information intensity is the level of detail with which objects and features are represented (MacEachren et al. 1999). This has a direct link to the first factor because the realistic structure and textural details of the represented objects contribute to the immersion of the renderings in a geovisualization.

A consideration of information intensity is the choice of level of detail utilized at any given scale. This is to ensure there is enough realism that is expected to be observed at a particular distance and the level of detail increases with increasing proximity to objects as would happen in the real world (MacEachren et al. 1999). In this work, immersion is demonstrated by using multi-scale data input, 3D perspective views and an animation flythrough at the landscape scale. Using multiple views at different scales helps to provide a dynamic level of detail in a photorealistic virtual environment. However, the limited real-time interaction is a compromise with more realistic modeling and rendering due to the computational power required for both real-time interaction and realistic rendering. This tradeoff is part of the visualization design and decisions must be made upfront to determine if it is sufficient to provide realistic views with set perspectives or provide interactive real-time views with more abstracted representation and simplified geometry. In some cases, both options may be separately pursued to provide further options for users of geovisualizations.

Slocum et al. (2001) noted that traditional 2D cartographic displays provide advantages by abstracting the real world so complex phenomena can be accurately and effectively represented. Since the world is far too complex, proper abstraction is needed to truly make sense of it (Slocum et al. 2001). This point emphasizes the importance of refining data sets and assessing the optimal design for visualizing data in a photorealistic environment. The need for cartographic principles such as generalization and abstraction remains in geovisualization techniques in order for intended information to be conveyed by the visualization results. Even though data may be represented with realistic objects, the data and the objects representing them should maintain the inherent levels of abstraction associated with the data resolution and the scale of acquisition, processing and storage. With the intention of accurately describing various data with transparency, realism associated with landscape visualization software should be utilized to generate understanding rather than confusion and misleading of users from the intent of a particular visualization.

Graphics Technology and Geovisualization

The link of graphic arts to botany (Deussen and Lintermann 2005) is a relationship that has been nurtured by evolving computer technology and the need for virtual simulation of natural environments in industries such as digital media, film and the arts, scientific illustration and geospatial sciences. The acceleration in 3D rendering capabilities of high-end graphics hardware found now in many standard PCs provides access to high quality rendering, enabling the creation of interactive dynamic virtual environments with complex and realistic scenery. In addition, the link between 3D graphics development and geovisualization is now becoming a "tighter" interplay since the theoretical and technological advances are dependent on one another (Döllner 2007).

By far, the most important and complex aspects of generating a virtual forest involve the efficient and effective modeling of vegetation. These plant elements require high levels of realism, yet due to their complex forms, also require the highest use of computational power. In order to accommodate higher levels of details and realism, methods for efficient modeling of botanical expressions and plant growth forms have been developed (Deussen et al. 2002). Since the 1960's, advances in the modeling of complex plant structures have included: 1) using simple 3D-symbols; 2) applying texture "maps" to these symbols and generating more realistic symbols (Fig 2.3); and 3) detailed modeling of plant structures utilizing formal plant modeling algorithms (Muhar 2001). Algorithms that have been historically utilized include: 1) simple fractal structures where principles of self-similarity are used for the basis of botanical construction in a visualization system (Fig 2.4); 2) L-grammar, which provides a formal language for the mathematical description of plant structures emulating their growth in the real world from an initial apical bud to stem development to leaves (Fig 2.4); and 3) AMAP or Tree systems models which avoid the deterministic approach of L-grammar by utilizing a stochastic model and basing the form on a specific statistical probability. These stochastic-based models require the driving parameters to be from field data and are thus very time consuming to implement (Muhar 2001).

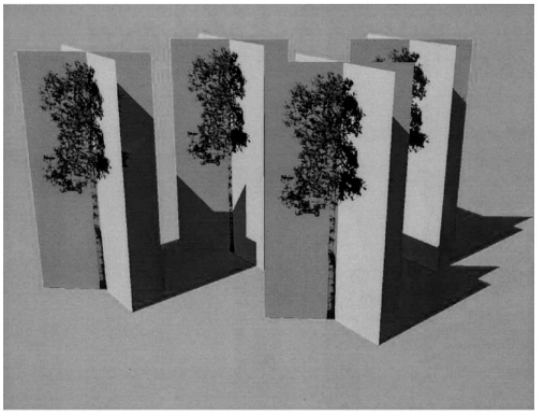
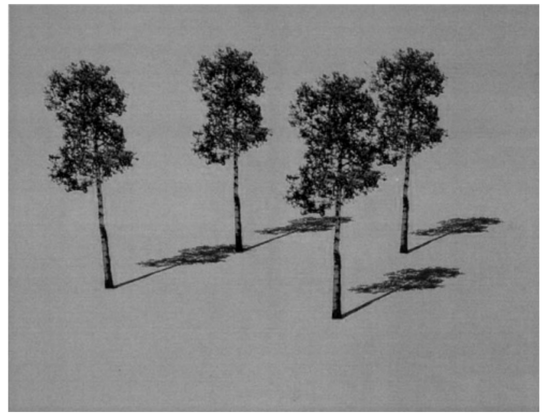
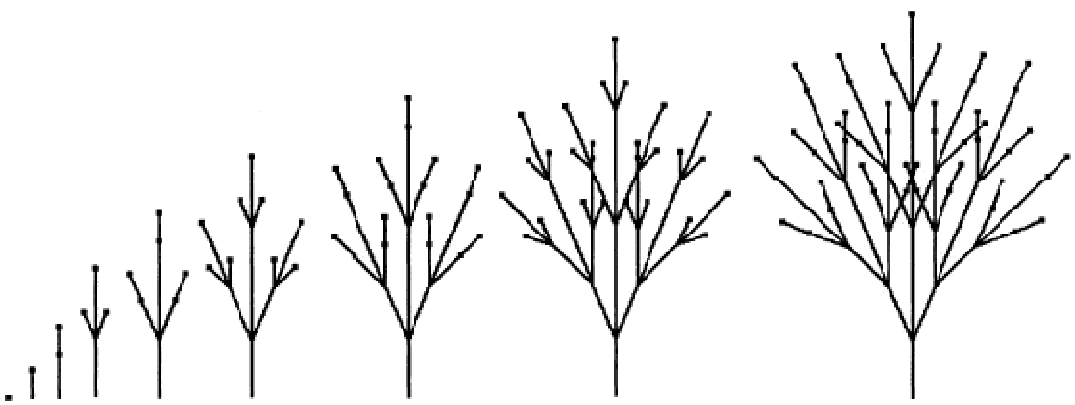
a  b 

Figure 2.3 (a) One of the more simple ways of realistically presenting plant forms is using a “billboard” upon which an image can be mapped as a texture. (b) The background color (often an alpha channel) is rendered as transparent and with multiple “boards” one image faces the camera while the other casts a shadow.

a



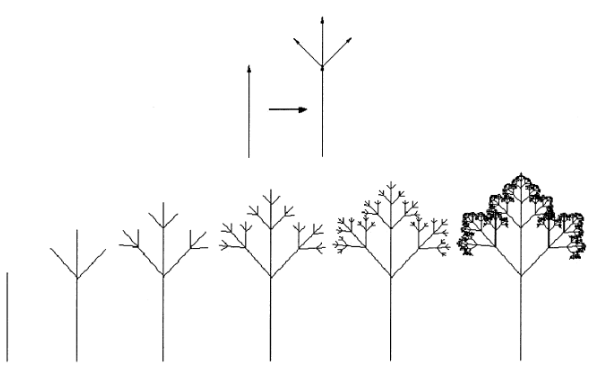
b  c 

Figure 2.4 (a) the L-system or L-grammar approach emulates natural plant development, (b) a fractal-based rule for creating plant structures, and (c) a simple 3D model with polygons upon which images of leaves and bark can be “mapped” as textures (from Muhar 2001).

Individual Plant Models

The proprietary software used in this project for generating plant forms was Green Works' Xfrog (http://www.xfrogdownloads.com/greenwebNew/products/productStart.htm). The developers noted two distinct goals with this particular approach to plant modeling: simulate the development of natural plants and generate visually correct shapes and forms of plants (Lintermann et al. 1999). Deussen et al. (2002) specifically mentioned three design forms such as L-systems, parameterized algorithms, and object-based components used in regard to the development of the Xfrog system. Accordingly, the botanically centered L-system, which specified plants in terms of local growth rules and the parameterized AMAP systems, which allowed more customized control over the procedures for plant modeling and still focused on botanically-based principles, were both cited by Xfrog developers (Lintermann et al. 1999). According to the developers, problems with the aforementioned approaches stemmed from the lack of a friendly user interface that maintained a geometrically-based model adhering to botanical principles. Striving towards computationally efficient object-based organization and the botanically accurate algorithms mentioned previously, Xfrog, then, utilizes a graph-based and component organized approach in which the graph represents structural information of the plant and the components link algorithmically structural information in a hierarchical manner. Lintermann et al. (1999) described the system as follows (refer to Fig 2.5 and 2.6):

Components (A to D) … form the p-graph, and the resulting i-tree. Component prototype C generates three instances of D, namely D1, D2, and D3, according to its local multiplication parameter and connects C1 to them. The recursion defined on prototype D forms a sequence of threeinstances—Di1, Di2, and Di3. This causes nine instances of D to take place in the final tree…. Local coordinate systems calculated separately for each child instance of a multiplication component—produce the differences in the orientation of the nine instances' geometries. Additionally, each component executes a geometry generation method triggered by its parameters (Lintermann et al. 1999).

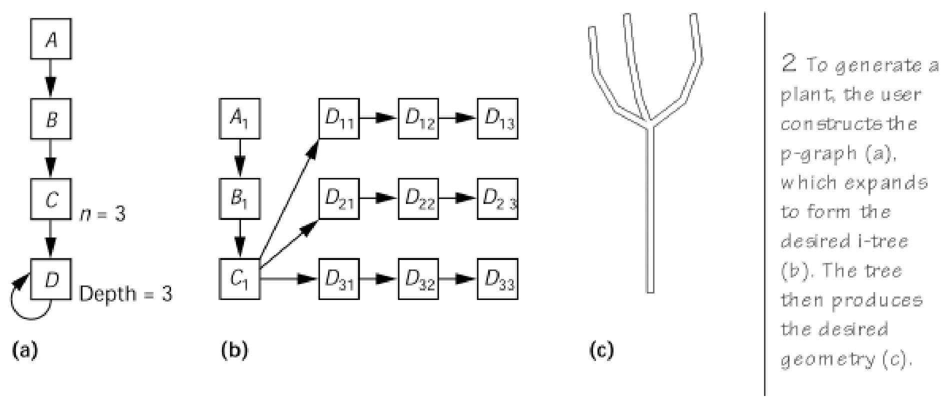


Figure 2.5 High level units (also refer to Xfrog interface in figure 2.6) are intuitive for user interaction and powerful for generating structures, yet they are optimized for conserving computational power by utilizing components to multiply the geometry (From Lintermann et al. 1990 and Deussen and Lintermann 2005).

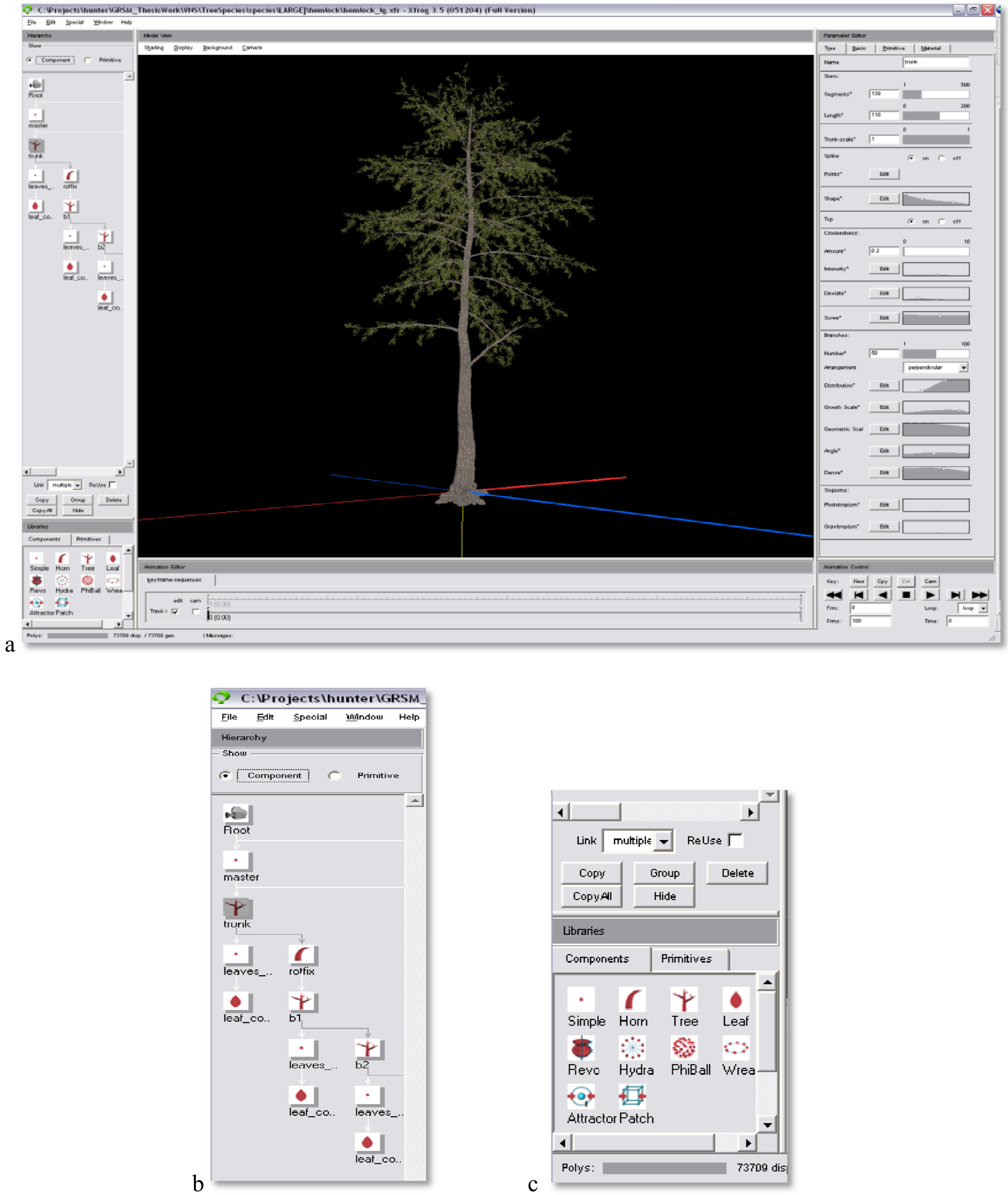


Figure 2.6 Screen shots from Xfrog interface show the way in which the user can utilize the principles outlined by Lintermann et al. (1999) (Fig 2.5). Tree models in the interface (a) can be generated using the concepts of hierarchical components and (b) developed into a user friendly scheme. The components consist of geometric primitives (c) that each can be modified and parameterized. The linking of components with a local multiplication parameter allows for efficient branching where modifications can be made to all the branches of each level through only one component.

Deussen and Lintermann (2005) offered another method to understand the interactive system of Xfrog described previously by Lintermann (1999) (see Fig 2.5). It is essentially a rule-based object production where the plant is represented by a combination of components that form the basis of the plants geometry. The parts of a plant are distributed algorithmically and thus components are parameterized over a multitude of objects, such that respective characteristics and orientations may be maintained. The connected components form the p-graph in Figure 2.5 which represents the rule system. The parameters of each component are enabled in the edges of the graph, so that the geometry of the "father" component invokes the production of the geometry for all its children. The use of an intermediate i-tree, or geometric temporary tree, allows for fast production and the multiplication component labeled as "Depth 3" in Figure 2.5 and allows for the dissemination of multiple geometries that are all copies of the father component.

This system allows for interaction which gives immediate control over the construction of organic forms, so that the user can visually construct plants, make modifications and immediately see the model respond to the changes. An advantage to this approach is that the user never loses sight of the information being processed "behind the scenes" of the software. Despite the fact that actual field data or biological parameters are not introduced directly into the model, the control over the system provided through rule-based procedures avoids the mystery of what may be happening with the data and instead provides direct transparency so that "what you see is what you get". This approach is far more efficient when generating many realistic unique plant specimens for a large landscape.

Terrain Modeling

After individual plant models, the next hurdle in efficient modeling of virtual landscapes includes the placement of individual plants on a modeled terrain. Both terrain modeling and vegetation modeling must utilize techniques that allow for sufficient realism with minimal computational use. Terrain is the logical predecessor to vegetation placement in the landscape, and for many visualization packages such as VNS, the modeled terrain has constraints, or rules that contribute to the distribution and the level of detail that is found in rendered vegetation.

The manner in which terrain data are used in a visualization platform such as VNS should be understood since most rendering engines in virtual systems must actively work with the terrain data in order to achieve accurate levels of detail and efficient rendering. Although many software packages, VNS included, are not open source, general principles found in the graphics community mention how original DEMs are usually tiled and processed using a variety of methods. These terrain processing methods include using a Brownian fractal function where elevation data are stored using a height map and each place on the surface denotes a specific elevation value interpreted as a function over the surface (Deussen and Lintermann 2005). One way a Brownian fractal motion is generated in virtual systems is similar to that of a Fourier transform procedure where the function is synthesized by sine functions which then result in Weierstrass-Mandelbrot functions (Deussen and Lintermann 2005). Other methods mentioned include band-limited noise functions and geometric polygonal subdivision with midpoint displacement. Ultimately, the variation gained using a fractal dimension can be manipulated to achieve local changes in the modeled terrain that simulate increased detail in the forest canopy texture (Fig 2.7). Often this introduced variability is applied to generated terrain in the virtual platform, but in some cases these controls are available to all terrain models imported into a virtual system. Therefore, it is advised that when utilizing such systems to take note of how terrain models are affected through specific constraints and parameters available in the software so that the placement and distribution of vegetation is understood in regards to the terrain. In some cases, the results may be realistic, but they may be inaccurate representations of the original data. Beyond the active control over fractal dimensions, there is the necessity of efficiency or appropriate LoD for realistic rendering output. This often mandates that these and similar approaches be used for efficient use of computational resources without disclosure.

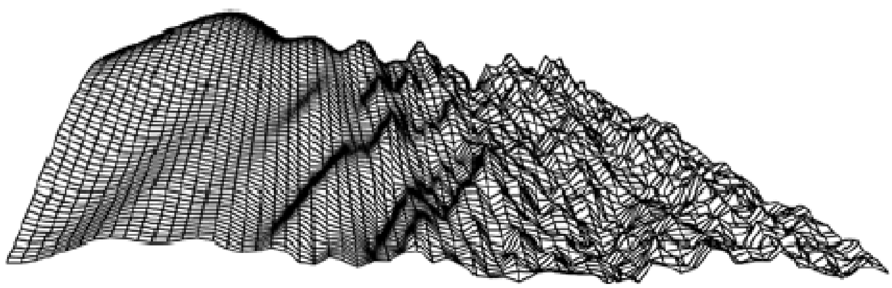


Figure 2.7 Fractal terrain with varying fractal dimensions increasing from left to right (From Deussen and Lintermann 2005).

<u>Vegetation and Landscape Rendering</u>

When incorporating 3D plant models and modeled terrain in geovisualizations, the effort to create a simulated distribution of realistic vegetation and the rendering of the virtual terrain quickly becomes a monumental task. Following the Deussen and Lintermann (2005) example, the process can be effectively explained using a modeling and rendering "pipeline". This pipeline model is an appropriate conceptualization of the procedure and here serves only as an example of one way to approach generating a system for virtual landscapes. In their pipeline, data are independently produced in various stages where each stage is followed by a lower abstraction of the prior stage and the final result is a purely geometrical description of the landscape. The overall procedure is divided into four subareas including the production of terrain (and soil) factors; the specification of plant distributions; the modeling of single plants; and the generation of rendered images. These general subdivisions formed the basis of more precise modules that, in turn, formed open system architecture (Fig 2.8).

A key feature of the pipeline is the quantization procedures (see Fig 2.8), which reduce the quantity of the geometric data of the plant models. This quantization approach is a method of optimizing the representation of plant distributions so that only a handful of instances of the model are modified and distributed randomly across the landscape. In addition to quantization, procedural model descriptions are used for processing before rendering. Positional information and the actual geometry of the plants are only utilized just before rendering so only the essential data needed for the processing procedures before rendering are used and the efficiency of the system is increased (Deussen and Lintermann 2005).

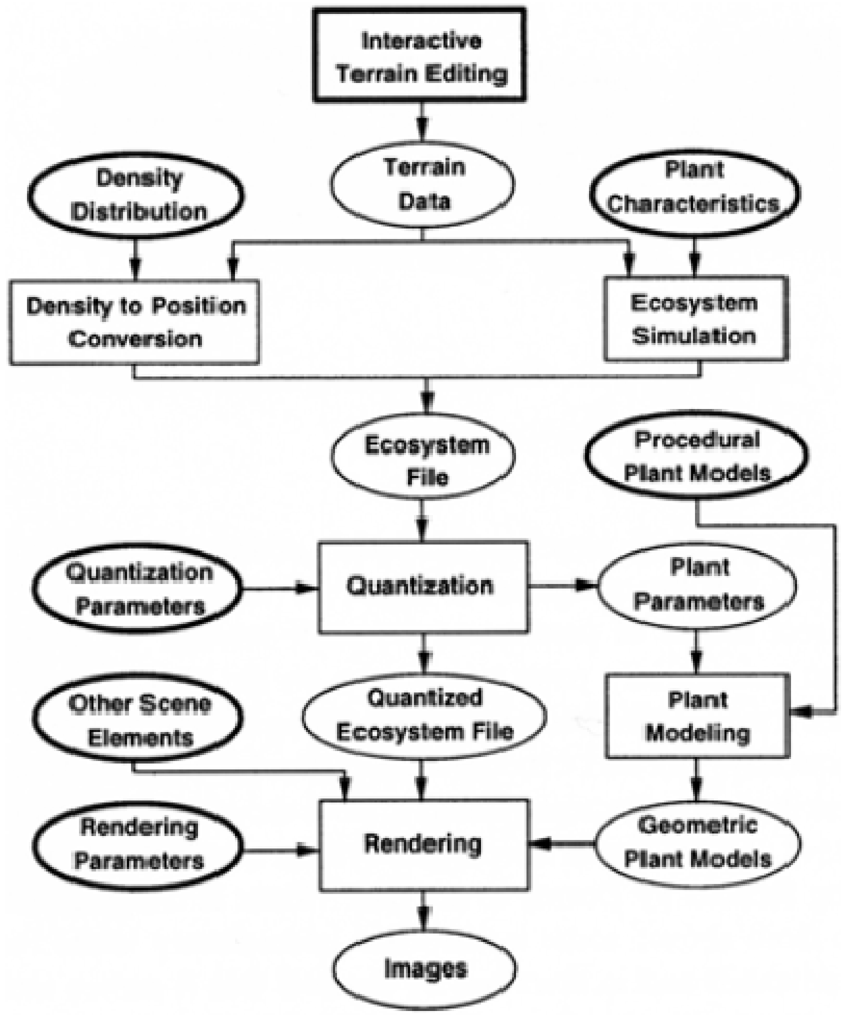


Figure 2.8 The open system architecture for visualizing ecosystems proposed by Deussen and Lintermann (2005).

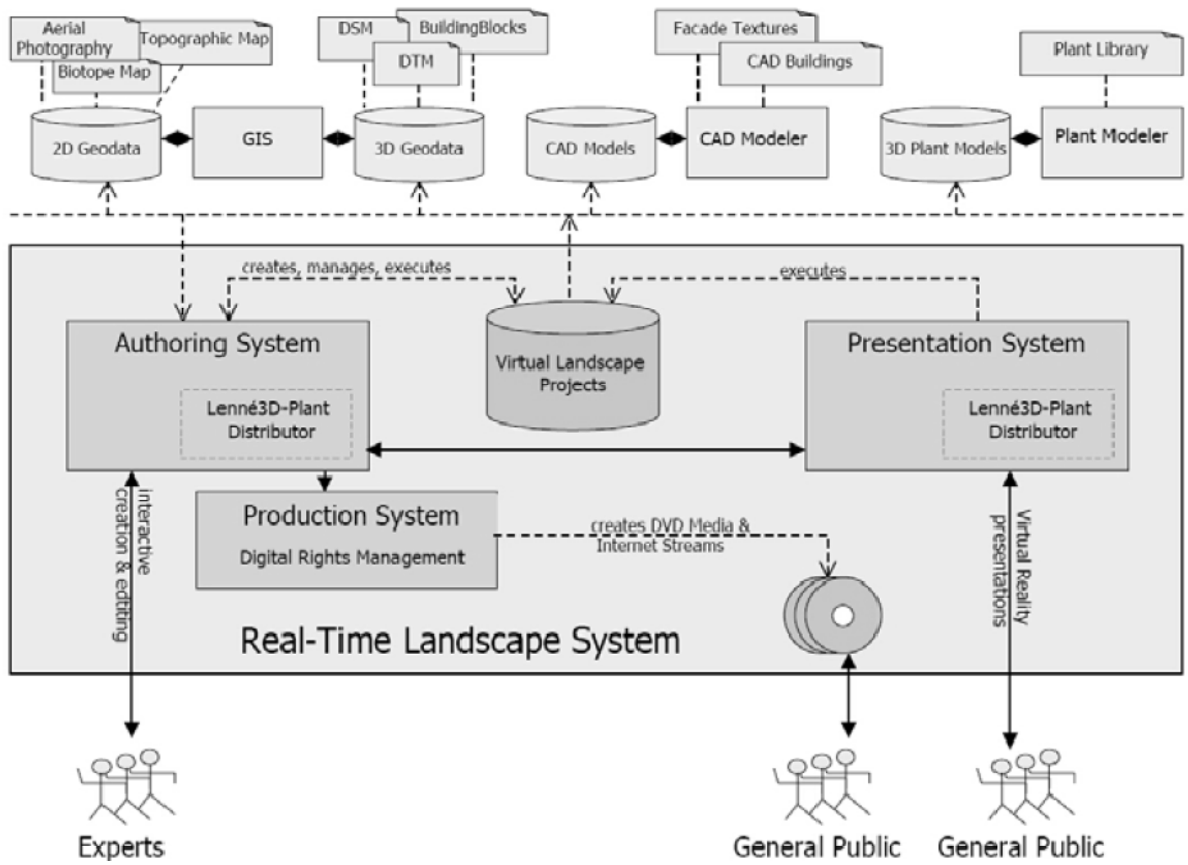


Figure 2.9 This example of a conceptualized visualization system is based on the LandXplorer system (Döllner, 2007).

In reference to an implemented application, Döllner's (2007) discussion of the LandXplorer (Autodesk Inc.) system offers a more specific description of a real-time landscape system (Fig 2.9). In Döllner's example, the two main components are the authoring and presentation systems. Each of these depends on the plant distribution subsystem where the instantiation, placement and configuration of the plant objects occur. The authoring system is the tool for constructing and designing the virtual landscape based on three object sets: geometric objects (representation of geo-data and geo-objects); behavior objects (specify interaction and animation details including that of the camera); and structure objects (hierarchically organize the components).

Each of these examples point to ways of handling the complexities of the data involved in depicting a virtual environment prior to rendering. The rendering procedure in Döllner's example utilizes level of detail algorithms that are based on a point or line simplification scheme. Accordingly, only vegetation objects close or directly in front of the camera are rendered with their full details, and the other vegetation instances are approximated with 3D points, lines or billboards that resemble the overall geometry of the objects (Döllner 2007). Combined with ongoing improvement of computational power and modeling procedures, realistic tree images can thus be created easily and developed with multiple views (of a single 3D model) to provide variation within the represented species (Wang et al. 2006). This efficient use of level of detail in a virtual environment allows the user to "walk" or "fly" through a landscape and view 3D objects from different directions.

Considerations for Visualizations

Many uses of landscape visualizations have been in the realm of landscape, urban planning and forestry planning, depicting the results of various forest harvesting practices, development scenarios, or impact assessments (Sheppard, 2001). In forestry planning, Cavens (2005) points out how important visualizations have become, noting that visually conveying information can help managers justify particular decisions and allow for the inclusion of public participation in management and forest planning processes. In fact, the long history of using visualizations in forestry developed around the need to manage the visual impact of traditional forest harvesting practices.

In addition to using landscape visualizations for management decisions, they have also been used as descriptors of forest dynamics and processes. For example, Dunbar (2004 and

2009) and Song et al. (2006 and 2008) used landscape visualizations to describe forest cover change following anthropogenic and natural disturbances, demonstrating the potential of visualization as a tool for communication in these types of more complex scenarios (Fig 2.10 and 2.11). As mentioned by Cavens (2005) and illustrated with work from both Song et al. (2006) and Dunbar et al. (2004), visualization is a very powerful and engaging tool that allows users to see how virtual landscapes change over various spatial and temporal scales.

Dunbar et al. (2004) developed both static and animated renderings illustrating three scales of forest cover change due to fires in Yellowstone National Park and urban development in northeastern Kansas. Visualizations of the Yellowstone fires reveal how landscape visualizations highlight ecological characteristics of post-fire vegetation succession. Utilizing specific landscape visualization tools, Dunbar was able to build virtual ecotypes. "Each ecotype consists of groups of image objects each with their own height range and density specifications." (Dunbar et al. 2004) This building of ecotypes in landscape visualization platforms such as VNS (Visual Nature Studio from 3D Nature, LLC, http://3dnature.com/) integrates data obtained from very high resolution imagery and a GIS by using linked polygon topology as the driver for ecotype placement with rendering methods included in VNS (Dunbar et al. 2004).

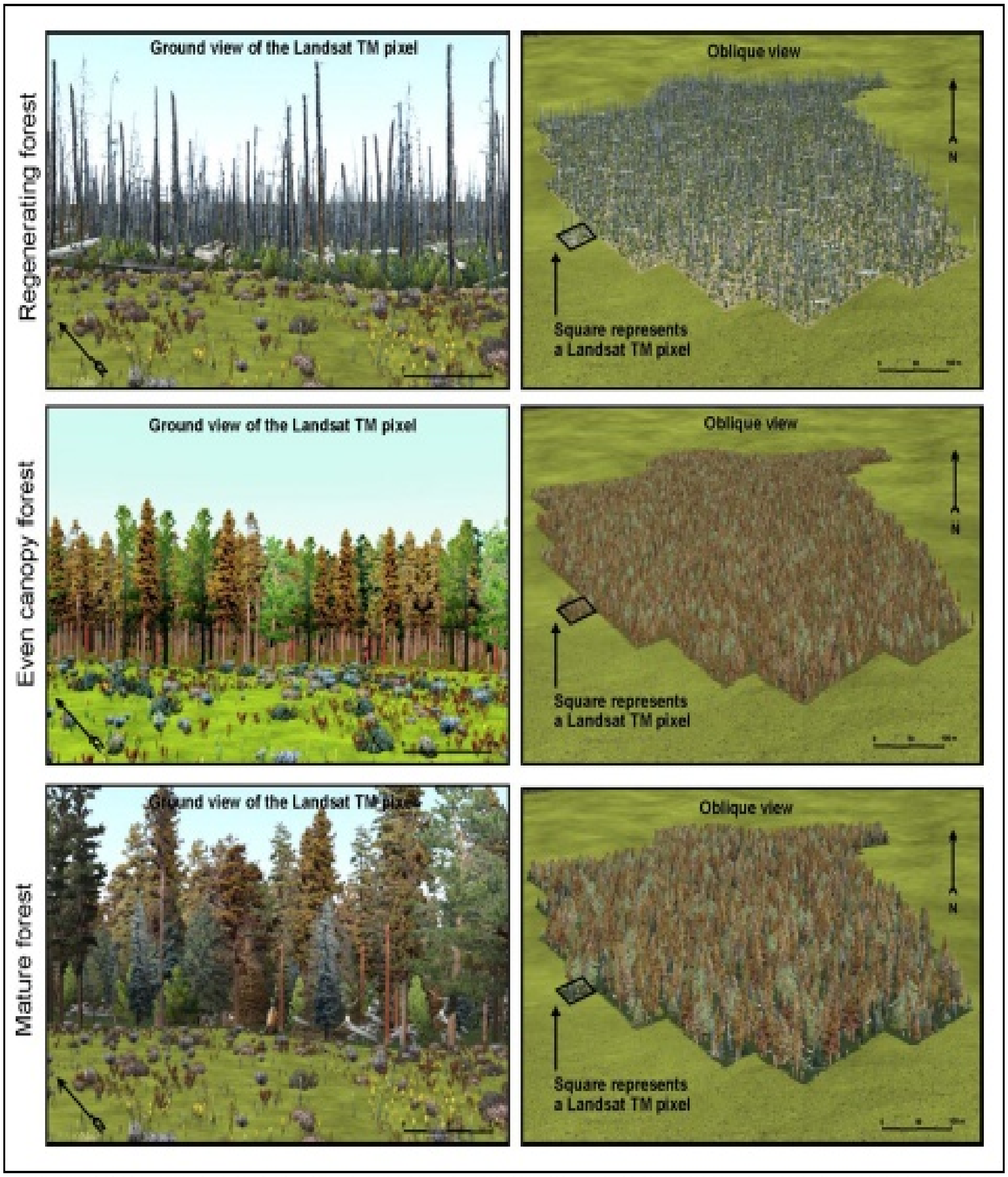


Figure 2.10 Renderings from Visual Nature Studio ecotypes representing three different successional stages of the Yellowstone lodgepole pine forest following fire. (Dunbar et al. 2004)

Song et al. (2008) used similar visualization techniques and included the generation of individual, realistic tree images of specific vegetation types integrated with remotely sensed data and GIS geodatabases (Fig 2.11). Their approach utilized a similar multi-scale approach to what is proposed for this work focusing on different forest management approaches. The emphasis of

Song et al. (2008) was on the realism needed for individual trees to “mimic” complex forests. Their approach utilized real tree images taken in the field (edited for use in the visualization) and tree models. Song’s work emphasizes the potential to incorporate further detail and realism by employing the use of 3D vegetation models to complement the finest scale renderings. Problems to note, though, included the issue of capturing high quality tree images with consistent lighting, shadows, and color range from a variety of angles (Song et al. 2008). One way around this, as proposed in this study, would be to use 3D modeling exclusively with images of species as textures to generate both 2D models and also use 3D models at fine (ground-based) scales.

a

b

Figure 2.11 Song et al. (2008) used three scales (a) to describe different forest management practices (b).

As evidenced by examples from Dunbar (2004 and 2009) and Song et al. (2005 and 2008), the amount of realism, the level of user interaction and the quality of information gleaned from any visualization is dependent upon the data resolution (both spatial and spectral), data fidelity or how well the data represent any particular phenomenon, and diversity of data sources. Data representing various aspects of the phenomenon being described are essential and add to the realism of visualizations. In the case of complex phenomena such as forests, these details help to establish valid representations of forested ecosystems (Lange 2000). From the scientists' perspective, details such as species composition and change in light penetration, for example and for lay persons the realism provided by shadows, color and texture are essential to provide both quantitative and qualitative aspects of a phenomenon and better evoke the "feel" of a place in the landscape. Both of these aspects need to be addressed, along with other details, to provide surrogates for aiding the comprehension of virtual landscapes (Williams et al. 2007).

Whether aesthetic or factual, accurate information about the biophysical elements in a landscape is essential for effectively conveying concepts of landscape dynamics including anthropogenic and "natural" biotic disturbances. Viewer's interpretation of dynamic landscapes in a geovisualization provides the interface between real-life experiences and the virtual, idealized world. The methods and approach of the geovisualization also allow for the articulation of scientific communication in a visualization scenario. The visualizations should provide just enough information so that the research questions that have been set forth can be resolved (Lange 2000 and 2005), yet they should provide enough realism to promote interest. Ultimately, data must be generalized to meet the goal of the visualization and in cases such as HWA in GRSM, the ecological information should be properly represented.

Consideration of the audience is often paramount to refining the scope and levels of detail involved with landscape visualizations (Lange 2005). Williams et al. (2007) mention the intended use, the interest and knowledge of the audiences are "vital considerations" in the development of visualizations. The selection of elements to include in visualizations and how to include them should be made in light of understanding the "selective nature of human perception" (Williams et al.2007). The refinement of visualizations in tune with this understanding of the "social and active nature of environmental cognition" is based on the producers' understanding of the particular elements in a landscape that viewers must utilize in making management judgments and the purpose of showing the visualization to the audience (Williams et al. 2007).

With the relatively recent wealth of publicly accessible geospatial data through various local, state and federal GIS clearinghouses and the willingness of some researchers to share the results of their works, general data acquisition for visualizations is not terribly difficult. Up–to-date and spatially detailed information, however, is not so easily found. Visualizing the complexity of forested landscapes particularly requires extensive ground work and can quickly become labor intensive and expensive (Wang et al. 2006) Despite these often compromising situations of data availability and required details, the use of public data have allowed much to be accomplished in visualization. In addition to available imagery from sites such as the University of Maryland's Global Land Cover Facility, USGS (U.S. Geological Survey) EROS Data Center, other online data sources such as the U.S. Department of Agriculture (USDA) Forest Inventory and Analysis (FIA) program or NatureServe (see Table 1 for details) offer accessible ground-based databases that may be appropriate for stand-level visualizations (Wang et al. 2006).

The use of remote sensing has proven vital for describing not only the HWA, but also other insect defoliators (Bonneau et al. 1999, Orwig et al. 2002, Koch et al. 2005, Leckie et al. 2005; Pontius et al. 2005, Coops et al. 2007, Hall et al.2007, Linke 2007). This project depends heavily on the use of remote sensing technologies which provide information and data for monitoring disturbances at a variety of scales and documenting the effects of disturbances across the landscape. Geographic information systems and remote sensing are more than just tools.

They represent “essentially new approaches to forest disturbance and spatial pattern mapping and analysis because they enable new ways of viewing disturbances and landscapes which in turn influence our understanding of management practices” (Linke et al. 2007).

Locating proper data sets that offer information linked specifically to the goals of visualization is not always easy and the data are not always cheap. Effective use of visualization is understandably dictated by the cost of producing the visualizations. In fact, if there is no efficient way to produce the visualization, then the need for this type of technology will simply be passed over and considered superfluous. What often dictates the adoption of any new methodology is its ease of use and efficient implementation. The use of public data sources, therefore, becomes more important and critical since all visualizations are only as good as the data sources; and the only thing that is better than good data is good, free data.

CHAPTER III

STUDY AREA

Originally designated as a park in 1934, Great Smoky Mountains National Park (GRSM) was later designated as an International Biosphere Reserve in 1976 and a World Heritage Site in 1983. The park is located in the southern portion of the greater Appalachian Mountains along the border of North Carolina and Tennessee (Fig 3.1). It is one of the most bio-diverse regions in the world and contains the largest area of virgin forest in the U.S. (Jenkins 2007). Elevations ranging from 267 to 2025 meters create a varied and rugged topography. The geologic makeup, dominated by metamorphosed sandstone along with other mafic, slate and limestone formations, creates the variable soils found in fertile valleys and the rocky outcrops found on higher ridges (Jenkins 2007). Other rock formations in the region are sedimentary resulting from silt, sand and

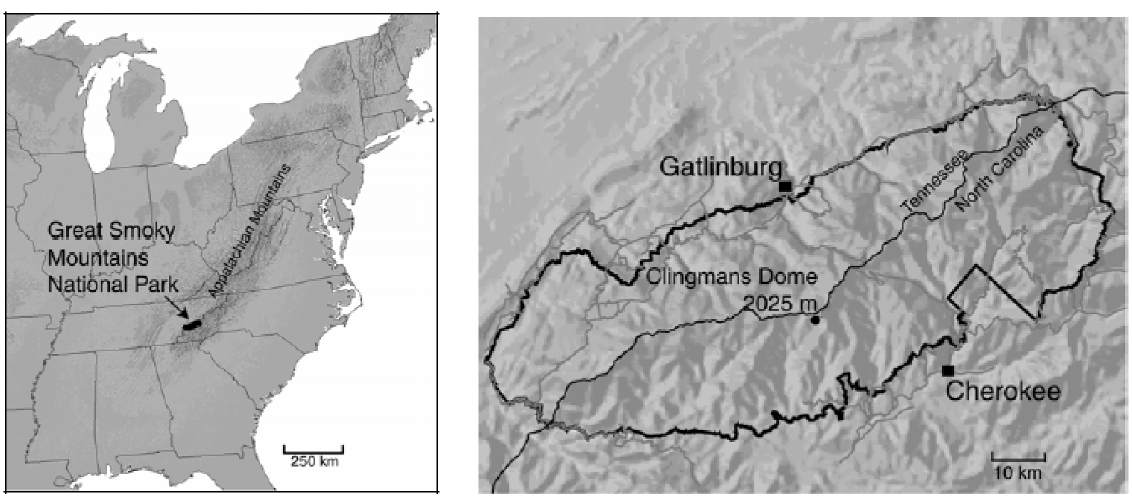


Figure 3.1 Location of the Great Smoky Mountains National Park in the southeastern Appalachians of the U.S. (Welch et al. 2002).

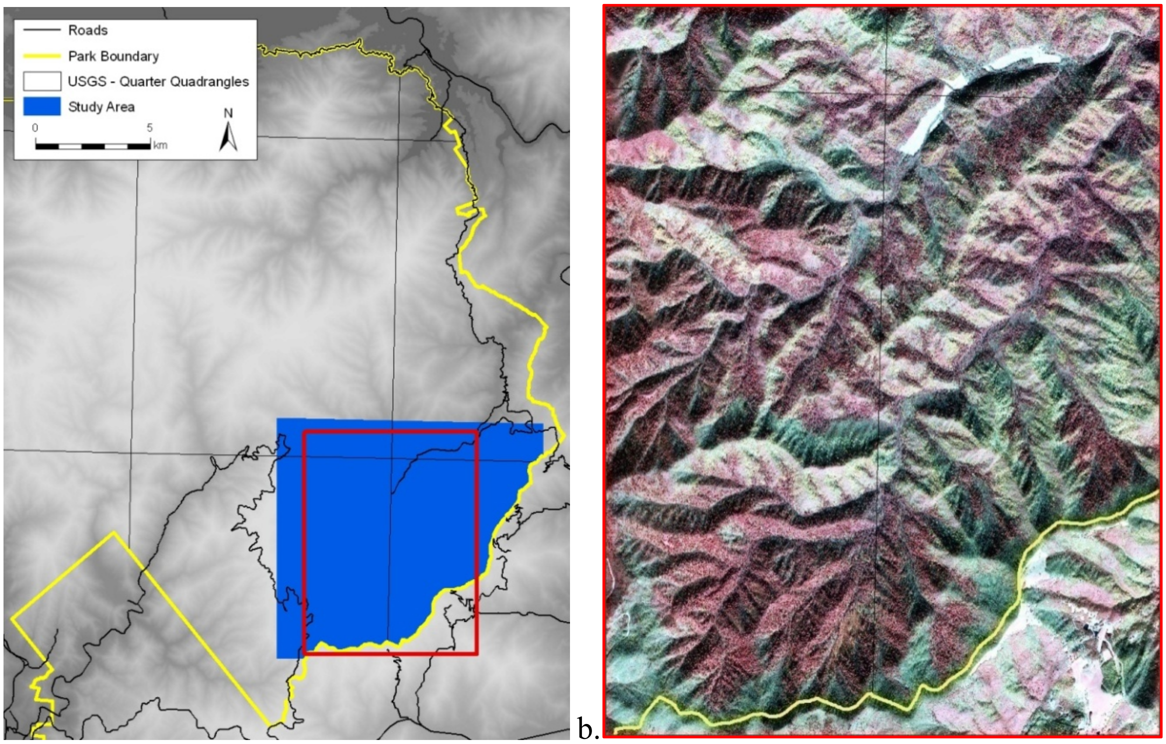
gravel deposited into a shallow sea that covered the area approximately 600 million years ago (Moore 1988). Annual rainfall in the park varies from 140 cm at lower elevations to well over 200 cm at higher elevations.

The diverse physical terrain with abundant rainfall and warm temperatures combine to create ecological gradients that result in a unique mosaic of diverse vegetation communities (i.e., associations). The park contains at least 1300 native plant species, more than 1570 species of flowering plants (10 percent of which are rare) and over 4000 species of non-flowering plants (Walker, 1991). In spite of these high species counts, approximately ten years ago it was estimated that only 10 percent of the species in GRSM had been documented (Kaiser, 1999). Consequently, the All Taxa Biodiversity Inventory (ATBI) was initiated to attempt the first comprehensive study to identify all of the life forms found within the park (White and Morse, 2000). As one of the most biodiverse areas in the world, containing large tracts of primary forest, or forest that has never been logged, GRSM also contains some of the largest trees (including hemlock) in North America (Jenkins 2007).

Although designation as a National Park and world conservation area has minimized human impacts such as logging, there are continued alterations by biotic and abiotic disturbances that threaten vegetation communities in GRSM. Exotic insects such as HWA are not new to the park and, unfortunately, have historically proven to be most destructive (Jenkins 2007). The chestnut blight (*Cryphonectria parasitica* (Murrill) Barr), introduced in the early1900's, virtually destroyed all American chestnuts (*Castanea dentate*) in the eastern U.S. by the 1940's (Whittaker 1956) and the balsam woolly adelgid (*Adelges picea* (Ratzeburg)) wiped out much of the Frasier fir (*Abies fraseri*) populations in the 1970's (Jenkins 2007). Hemlock woolly adelgid may prove to be the contemporary example of the devastation that occurred with the decimation of American chestnut and Frasier fir, with similar consequences expected to the community structures in the forest of the Appalachians.

According to Jenkins (2007) there are 11 major types of vegetation alliances in the park which can be further divided into communities (i.e. associations of typical species). The defined unit of association was a "plant community type of definite floristic composition, uniform habitat conditions and uniform physiognomy" (Grossman et al. 1998). Generally speaking, the two major hemlock dominated associations found in the park are the southern Appalachian Eastern Hemlock type with or without white pine (*Pinus strobus*) (Shafale and Weakly 1990, Jackson et al. 2002). The shrub layers of the hemlock forests typically consist of rhododendron (*Rhododendron maximum*) and leucouthuie (*Leucouthuie fontenasiana*). The herb layer is usually sparse, but may include various fern species such as Christmas fern (*Polystichum acrostichoides*) and low growing herbs such as partridgeberry (*Mitchella repens L*.). Eastern hemlock is an important component of many Smoky Mountain forest communities and often occupies the area near streams and within cove/valley formations, typically on lower protected slopes and terraces below 2300 m (Shafale and Weakly 1990, Jenkins 2007). In communities where hemlock is not completely dominant, sites may be at higher elevations within or near northern hardwood forest community types (Shafale and Weakly 1990).

The Cataloochee Valley within GRSM was chosen as a study area because it provides some of the oldest and most extensive stands of hemlock in the park, and compared to other areas, was not historically as heavily logged. Visualizations for this study targeted Eastern hemlock habitats at three scales. Landscape, stand and plot-level studies focused on study areas in and around the Cataloochee Valley on the southeastern side of the park and corresponding to USGS 7.5 minute quads, Bunches Bald and



a. b.

Figure 3.2 The study area in blue, (a), lies within the southeastern section of Great Smoky Mountains National Park. This is the portion of the park that was updated with information on hemlock dieback due to HWA. The image at right (b) is the corresponding area outlined in red in (a) that is covered by a multispectral IKONOS image acquired in October 2003 by GeoEye, Inc..

Dellwood (Fig 3.2). Landscape-level (covering approximately 10 X 10 km) refers to the scale at which perspective views would encompass high levels of variability in topography, but little variability and details on vegetation communities and relatively coarse resolution of dieback patterns. The stand-level (on the order of 1 X 1 km in size) is that in which species variability is evident as well as the patterns associated with vegetation communities (i.e. associations), and the structure of the canopy can be clearly discerned. Varied topography is less important at the stand-level as the view is generally focused on a single hillside or slope. The plot-level (about .5 ha in size) renderings represent views that would be found if one were on the ground looking up and into the canopy. Species variability is represented at the plot-level, and emphasis in on the

3D structure of a single association type including detailed representation of understory and overstory species. The reason to include multiple scales is to take full advantage of the capabilities of any GIS and visualization platform by integrating scale dependent data sources into a single conceptual and geographic framework to address an ecological problem. The context of the hemlock dieback is not isolated to any one data source or scale, and a comprehensive view of the issue will offer the most insight into methods to mitigate its impacts.

CHAPTER IV

GEOSPATIAL DATA FOR MULTI-SCALE VISUALIZATIONS OF HEMLOCK AND HWA DAMAGE

Overview of Data Sources

The data sets used for visualizing changes in GRSM vegetation communities at the landscape, stand and plot-levels due to the HWA included satellite images of various spatial resolution, elevation information, airborne digital images, GIS vegetation data sets, and ground-based field data. Specific information on available data for this project follow in Table 4.1 and data sources for the plot, stand and landscape-levels are discussed below.

Table 4.1 Data sets utilized to create visualizations of hemlock damage and dieback due to HWA invasion in GRSM.

Data Set:	**Location/Resource:**
Imagery datasets	
Landscape Scale:	
ETM+	Global Land Cover Facility--> www.landcover.org.
IKONOS	GeoEye Archive
Stan Scale & Plot Scale	
IKONOS	GeoEye Archive
CIR	CRMS-->http://www.crms.uga.edu/great_smoky_mountains.htm
NAIP	USDA National Agriculture Imagery Program
Elevation datasets	
Landscape Scale:	
30 & 90 meter SRTM DEM	http://seamless.usgs.gov/products/srtm1arc.php
Stan Scale & Plot Scale	
3 meter DEM	NED-->http://seamless.usgs.gov/
LIDAR	North Carolina flodd mapping program
10 meter DEM	NC DOT: http://www.ncdot.org/it/gis/DataDistribution/ContourElevationData/default.html
Vegetation datasets	
Landscape Scale:	
CRMS-NPS vegetation dataset	Alliance level system: CRMS/NPS-->http://www.crms.uga.edu/great_smoky_mountains.htm
Stan Scale	
CRMS-NPS vegetation dataset	Association level system: CRMS/NPS-->http://www.crms.uga.edu/great_smoky_mountains.htm
NatureServe plots	http://www.natureserve.org/explorer/
Plot Scale	
Field work	personally acquired database
CRMS-NPS vegetation dataset	Association level system: CRMS/NPS-->http://www.crms.uga.edu/great_smoky_mountains.htm
NatureServe plots	http://www.natureserve.org/explorer/
Imagery/DEM	**Details/Specifications**
Imagery	
CIR	page 13 of final report: http://www.crms.uga.edu/nps/grsm/GRSM_Final_Report.pdf
IKONOS	**http://www.geoeye.com/CorpSite/products/imagery-sources/Default.aspx#ikonos**
NAIP	http://165.221.201.14/white%20papers/NAIP_final_2006_update.pdf
ETM+mosaics	ETM+:http://landsat.gsfc.nasa.gov/about/etm+.html
Elevation datasets	
3 meter	http://seamless.usgs.gov/products/9arc.php#
10 meter DEM	http://www.ncfloodmaps.com/pubdocs/lidar_final_jan03.pdf
LIDAR	North Carolina flodd mapping program: http://floodmaps.nc.gov/fmis/Home.aspx
30 & 90 meter DEM	http://seamless.usgs.gov/products/srtm1arc.php

Plot-Level Data

Ground-based information on various parameters of the forest structure in a hemlock dominated stand was required for renderings at the plot-level. This included diameter at breast height (dbh), hemlock and associated tree species densities, and information on other vegetation strata such as representative species found in the shrub and herbaceous layers. These plot-level details were only collected for specific sites of hemlock-dominated communities.

For information needed at the plot-level, the most detailed ground or object-level of visualization, field work was conducted at three hemlock dominated or co-dominated sites in the Cataloochee area of GRSM during the summer of 2008. Each circular site was chosen specifically for its representative vegetation association type (hemlock dominated) and each measured approximately 40 meters in diameter. At each site only tree species in the understory and overstory that had DBH of 5 cm or greater were documented. Percent species composition of herb and shrub strata were noted by

Figure 4.1 Example of a fisheye image of forest cover. Analysis of these types of images can provide percent cover and light penetration information that can be used at the plot-level (http://www.flickr.com/photos/dfluff/3525895657/)

a

b

Figure 4.2 Images taken on the ground at the center of the plot which was used for renderings in this study show (a) shrub layer including *Rhododendron maximum* and *Kalmia latifolia* and (b) sub–canopy-level with taller *Kalmia latifolia*, *Betula lenta* (sweet birch) and hemlock (largest trunks on right side of image) general observation. Sampling of the shrub and herbaceous layers was not necessary since perspective views obstruct specimen placement and prevent specific details on shrub/herb distribution and size to be discernable. The location of each tree relative to a central GPS coordinate for the plot was recorded with a distance and azimuth reading. Photographs for each species' bark and leaf were obtained for texture mapping performed during 3D vegetation modeling of individual trees and shrubs in Xfrog. Photographs also were captured with a 10-mm fish-eye lens (similar to Fig 4.1) which along with perspective ground photos (Fig 4.2), can be used to assess and compare light penetration, shadows and percent cover in the canopy. Each plot sampled had spatial, compositional, and lighting characteristics documented for detailed reconstructions in VNS.

Stand-Level Data

For the stand-level, plot-level details, and a vegetation data set (Fig 4.3) from the University of Georgia Department of Geography Center for Remote Sensing and Mapping Science (CRMS) provided the necessary information to derive stand scale descriptions of vegetation communities, landscape patterns, and hemlock dieback (Welch et al. 2002, Madden et al. 2004). Other available data sets such as field plot data collected by NatureServe, a non-profit organization that partners with the USGS and the National Park Service (NPS) to conduct botanical field surveys in support of the National Vegetation Inventory (The Nature Conservancy, 1999, http://www.natureserve.org), provided other details such as species composition, size class and density for each of the forest strata and offered details needed at both plot and stand-scale levels.

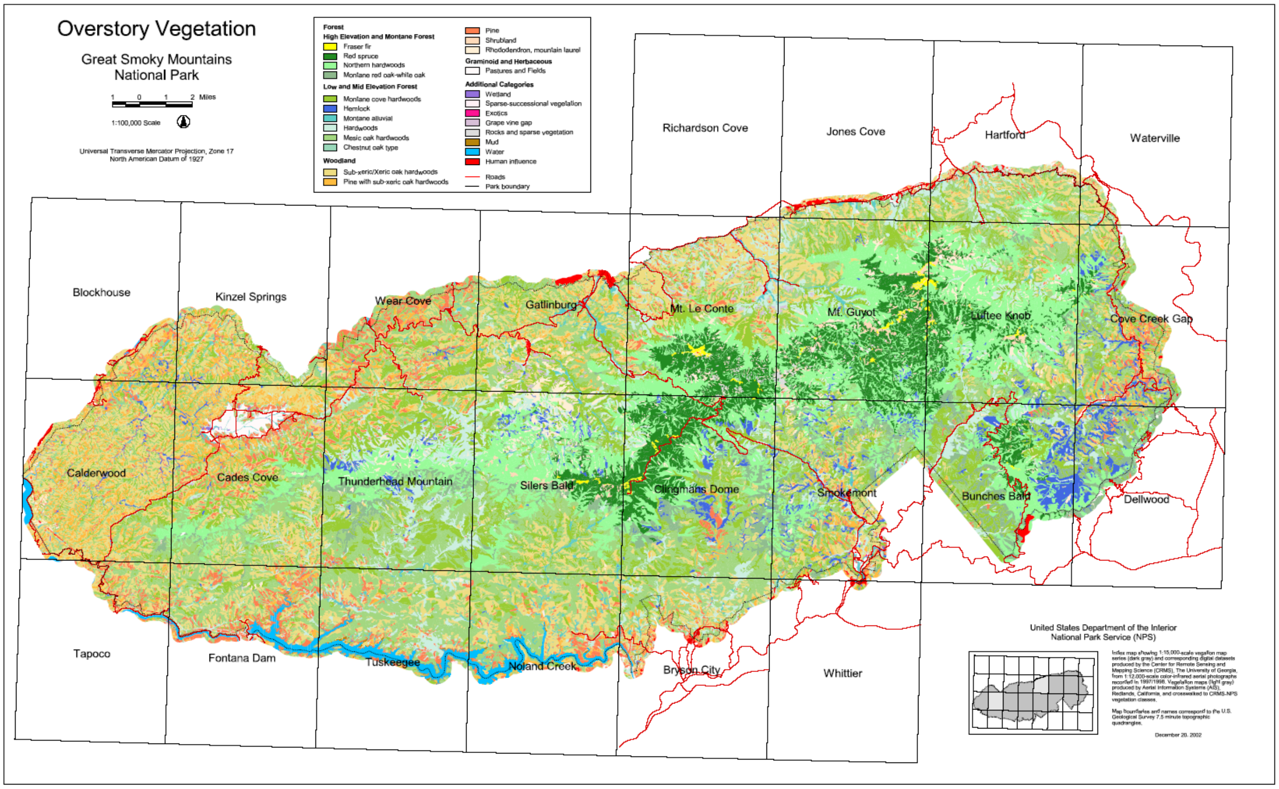


Figure 4.3 A map of the CRMS/NPS data set that was produced for overstory and understory vegetation associations of the entire park (Madden et al. 2004).

Initial design of the main stand-level database used in this project was for GIS analysis and the production of 2D choroplethic maps and not for 3D photorealistic representation. This issue is paramount when obtaining data for use in these types of visualizations since most data are initially acquired for purposes other than photorealistic realistic representation. Results of this work and of prior studies with photorealistic techniques (Wang et al. 2006) reveal that scenes quickly can be visually overburdened with representational objects from these databases. Consequently, existing GIS databases often must be generalized for use in visualizations.

Landscape-Level Data

The CRMS/NPS vegetation database was created from large scale (1:12,000) 1997-1998 color infrared air photos and thus depicts hemlock health and status before the invasion of HWA into the park in approximately 2003 (Sohen et al. 2005). More recent, high resolution image data from the 2006 USDA National Agricultural Imaging Program (NAIP) were used to describe the current pattern and extent of hemlock dieback within the study area referenced to mapped hemlock communities at the landscape scale. A comparison of historic (1997) and recent (2006) data sets was performed to derive changes in hemlock communities where symptoms of the HWA infestations have occurred.

At the landscape-level, both stand-level information from CRMS/NPS data and a raster grid of dead hemlock derived from the 2006 NAIP image (referred to as a "color map" in VNS) were used to place vegetation objects created in Xfrog into the "virtual" landscape. The NAIP image is a true color, digital orthoimage with a spatial resolution of 1 meter downloaded free of charge from the USGS Seamless Server (refer to Table 1 for links and further details). The results in this study use the "color map" option available in VNS which allows virtual ecosystems to be placed on the terrain-based on the location and value of image pixels. Due to the scale and discernable detail at the landscape views, this type of raster-based model provided a more efficient rendering of the views. Details on this type of procedure follow in the methods section.

Details on the CRMS/NPS Vegetation Database

Several GIS vegetation databases (Fig 4.3) for GRSM were produced by CRMS with funding by NPS (Welch et al 2002, Jordan 2002 Madden et al. 2004). The use of softcopy photogrammetric techniques (using 1997-1998 CIR air photos) and integration of GIS data were paramount to the completion of the vegetation data set due to the rugged terrain of the park (Jordan 2002 and 2004). These data provide vector polygons with a minimum mapping unit of approximately 0.5 ha for over 100 overstory and 70 understory plant communities (i.e., associations) plotted within +/- 5 to10 meters root mean square error (RMSE) of their true ground locations (Welch et al. 2002). These data were used in this work primarily for the stand-level visualizations.

A number of environmental factors in the Great Smoky Mountains and the southern Appalachians (e.g. elevation, slope and aspect, geology,soils, hydrology, local and prevailing winds) contribute to mesic to xeric gradients within elevation ranges of the park. Accordingly, general breaks in the plant community distributions occurred at 270 to 760 meters (lowlands); 760 to 1,220 meters (mid-elevation); 1,220 to 1,520 meters (high elevation); and 1,520 to 2,025 meters (sub-alpine) (Jackson et al. 2004) (Fig 4.4).

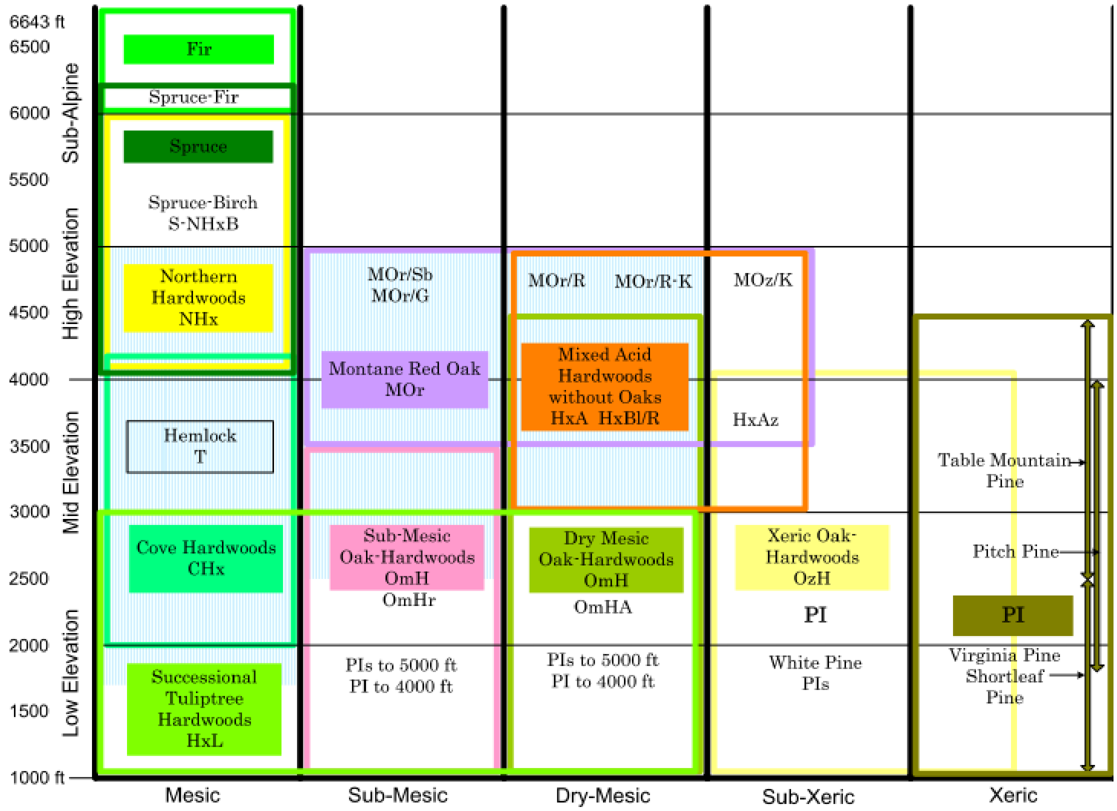


Figure 4.4 Ecological location of forest communities in Great Smoky Mountains with respect to elevation and moisture gradients. (Abbreviations are explained in Jackson et al. (2002), Vegetation Classification System for Mapping Great Smoky Mountains National Park).

The associations of the classification scheme developed by CRMS/NPS personnel utilized a NatureServe (formerly the Association for Biodiversity Information (ABI) of The Nature Conservancy) report of vegetation associations defined for an area corresponding to the Cades Cove and Mont Le Conte USGS topographic quadrangles (The Nature Conservancy, 1999, Jackson et al. 2002). Similar to earlier studies by Whittaker (1956) or Parker (1982), which relate plant distributions and environmental variables to available soil moisture, the organization of the CRMS/NPS vegetation classification system for GRSM was based on the "ecological location of forest communities with respect to elevation and moisture gradients" (Jackson 2004).

According to Madden et al. (2004), the overstory vegetation associations that are found in the CRMS/NPS data base were developed for this mapping project based on previous studies of southern Appalachian vegetation communities, input from park resource managers and field observations by CRMS ecologists (Whitaker 1956, Jackson et al. 2002). The resulting hierarchical classification system was later cross-walked to the U.S. National Vegetation Classification System (NVCS) (Jackson 2004, Seavey and Seavey 2004). Using ordination techniques based on existing reports and field data from over 400 vegetation plots, 42 alliances and 68 associations were described by NatureServe for the two quad GRSM study area. The CRMS/NPS classification system was expanded from these earlier studies into a hierarchical organization of plant associations for the entire park area by Jackson et al. (2002) and Jackson (2004). For this study, hemlock polygons attributed at the community or association-level were collapsed to create alliance-level hemlock classes as illustrated in Table 2 to facilitate efficient representation in the visualization.

Table 4.2 A generalization of Association-level hemlock polygons to the Alliance-level of forest classification for the CRMS/NPS Vegetation Database Classes Containing Hemlock (T)

Association-Level Classes	Alliance-Level Classes
T	Dominant T
T/NHx T/CHx T/S T/CHxA	Mixed T Dominant
NHx/T CHx/T NHxB/T	Mixed T Secondary
T- in 2nd Veg Attribute	Mixed T Minor Component
Other	No T

Digital Elevation Models

For this work, all digital elevation models (DEMs) were downloaded from publicly available servers (USGS, http://usgs.seamless.gov/) and are from the USGS National Elevation Datasets (NED). A 30-meter DEM was employed for views at the landscape scale, a 10-meter DEM at the finer stand-level, and a 3-meter DEM at the most detailed level of the project. Also, a DEM was generated in this study using the bare earth and canopy surface first return layers from a raw LIDAR database (North Carolina flood mapping program: http://floodmaps.nc.gov/fmis/Download.aspx) and was applied for canopy height variability at the stand-level.

CHAPTER V

METHODS AND APPROACH

Specific methodologies and workflow for producing photorealistic visualizations of hemlock dieback included the following:

1) A vegetation library of 3D plant models was generated for selected tree and shrub species that characterize GRSM vegetation communities (i.e., associations).
2) Subsets of data and derivatives were prepared for use in VNS using ESRI ArcGIS and ERDAS Imagine. The NAIP imagery was classified to accentuate dieback patterns at the landscape scale. All subsets and derivatives were imported into VNS to build "virtual" ecosystems at the plot, stand and landscape scales.
3) Renderings were produced within the VNS framework using ecosystem components, camera placement and animation controls. Still and animation sequences of rendered images focused on changing vegetation cover based on hemlock dieback from HWA. Post-processing was then performed for adding labeling and cartographic mapping elements.

Vegetation Library

A basic vegetation library of 3D plant models was created using Xfrog software based on information retrieved from NatureServe vegetation plots in GRSM and data gathered in the field. Xfrog was used to visually create 3D models with specific morphological and physiological characteristics of species commonly associated with hemlock. In this way, stem type, branching architecture, leaf type, and surface color/texture defined the colloquial appearance of a typical species for the field-based study area. Plant species added to the vegetation library also included other species found at the stand and landscape scale such as: hemlock (*Tsuga canadensis*), mountain silverbell (*Halesia tetraptera*), frasier magnolia (*Magnolia faseri*), red maple (*Acer rubrum*), sweet birch (*Betula lenta*), northern red oak (*Quercus rubra*), white oak (*Quercus alba*), chestnut oak (*Quercus prinus*), eastern white pine (*Pinus strobus*), mountain laurel (*Kalmia latifolia*), rhododendron (*Rhododendron maximum*), tulip poplar (*Liriodendron tulipifera*), and dog hobble (*Leucothoe fontanesiana*) (Fig 5.1). Each species was chosen for its contribution to key vegetation associations of the CRMS/NPS database or those found at the sampled field sites.

These are dominant species of each stratum (i.e., overstory, understory, and herb layers) within each dominant vegetation type as indicated from the CRMS-NPS, Vegetation Classification System for GRSM and NatureServe association descriptions (Fig 5.2). For instance, T (indicating a hemlock dominated stand) may also have at least 15 percent tulip poplar in the canopy of this type (based on NatureServe field surveys). The next species in the canopy listed in the NatureServe plot data represents only 3.5% composition and was not included. To be consistent, species of each stratum were included in the rendering at the plot and stand-level if they comprised 15% or more of the strata. However, in cases where there were very few species, at least two key species were included for the renderings. In the case of the hemlock polygons, there were two species in the canopy, hemlock (90%) and tulip poplar (15%).

Figure 5.1 Specimens from the vegetation library included here are (a) hemlock (*Tsuga canadensis*), (b) tulip poplar (*Liriodendron tulipifera*), (c) northern red oak (*Quercus rubra*), and (d) rhododendron (*Rhododendron maximum*)(not to scale). Note that images represented here are indicative of 2D-billboard renderings generated from 3D models.

This work utilized qualitative data collected in the field (such as ground photographs of bark and leaves) to produce the 3D vegetation models used in the plot-level visualizations. These 3D models, in turn, were used to derive 2D billboards for use at the stand and landscape-levels. Billboards serve as a way to map an image of the plant specimens on to a flat surface and allow for the simulation of 3D qualities without the need for a true 3D model with hundreds of thousands of polygons. Qualitative field work involved the acquisition of ground photos of the various vegetation communities that are dominated by hemlock, the adjacent or contiguous community types, and the respective stand strata. Images of canopy structure, sub-canopy, shrub layers, and herbaceous layers documented and verified the views and perspectives of typical hemlock communities. They also provided information on light penetration and textures that help in developing realistic renderings. In addition, GPS coordinates were captured with these photos,

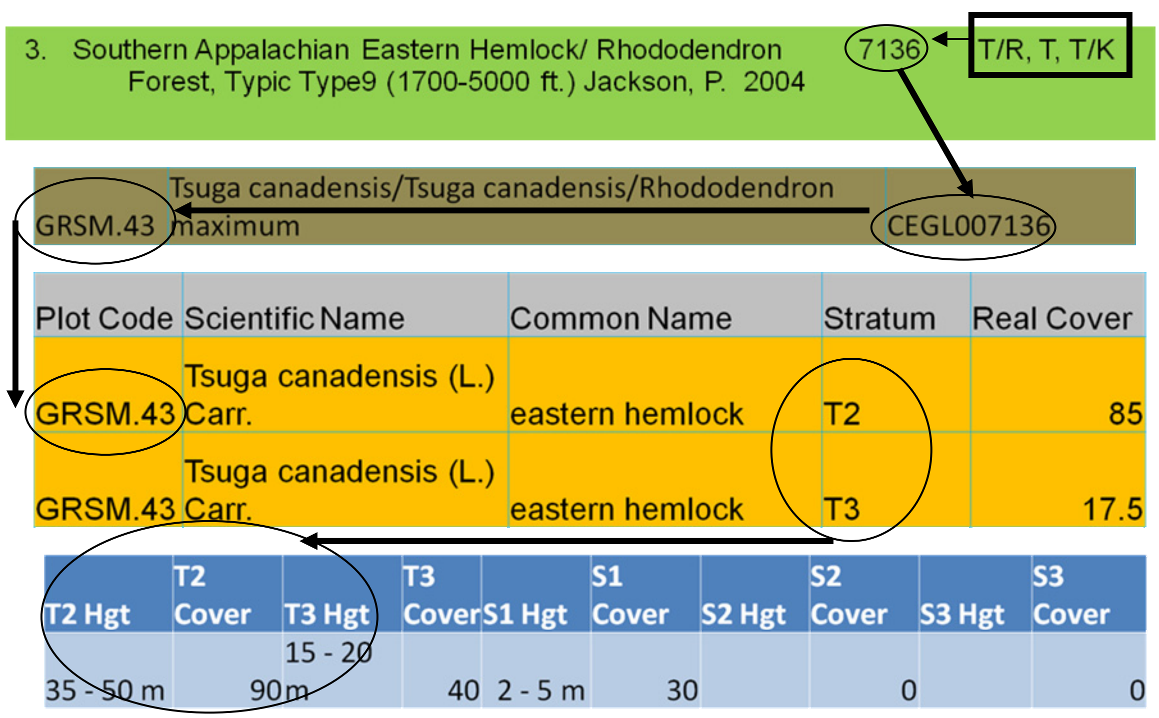


Figure 5.2 These exerpts from Jackson et al. 2004 and NatureServe plot data illustrate the link between polygon attributes from CRMS/NPS databases and details contained within the

NatureServe database. Polygon attributes of a T/R type (upper right, indicated by box) are crosswalked to CEGEL value 7136 and linked to the NatureServe plot GRSM.43. The resulting stand andstrata information for plot 43 is then utilized to recover ecotype components in VNS such as stratum T2 tree height (35-50-m) and percent cover (90 percent).

Figure 5.3 Photographs of sourwood (*Oxydendrum arboreum*) leaf (a) and bark b) and hemlock needles (Xfrog plant library) (c) and bark (d). The background in (c) has been converted to a transparent alpha channel.

along with notable species and photos documenting leaf structure and bark textures (Fig 5.3). This information is used in the modeling of the individual species in Xfrog by utilizing texture mapping of the images of leaves or bark onto the 3D model, which consists of polygons in 3D space. Images of leaves and bark for each species contribute to the realism of objects in the vegetation models and contribute to the colloquial aspects of specimens particular to these areas of the park and their respective communities. In other words, rather than use a generic hemlock tree found in the VNS plant library, the field work conducted for this study was used to derive the details of these species that are specific to this study site. The texturing of image objects to gain realism is often used and this realism has proven to be a decisive factor when producing representative, photorealistic renderings (Daniel and Meitner 2001).

Data Integration and Building Virtual Ecosystems in VNS

Data generally used in landscape visualizations start with a DEM that serves as the foundation upon which all other information is based. Software such as VNS includes the capabilities to manipulate DEMs in order to accommodate issues of scale and detail. Within VNS, DEM resolution-levels can be refined to coarser or finer resolutions to maximize display efficiency and data content without feasting upon computational power. These features, however, require advanced experience with the software and may alter data sets incongruent with project goals. With proper planning and available data, oftentimes these generalization tools may be curtailed all together by using multiple DEMs of varying resolution.

In addition to the 3-meter, 10-meter and 30-meter NED DEMs (see Table 4.1) used for representing the bare earth in the visualization, a LIDAR-based DEM was generated from raw LIDAR data (see Table 4.1) and was used to represent canopy heights. The first return and the bare earth layers were exported as ASCII files containing XYZ coordinates (.xyz extension) and two grids were generated based on each layer. The ground and surface grids were used in a raster math calculation in ArcMap to subtract the last return from the first return. The resulting grid provided 3-m cell values of interpolated canopy heights and was used as a texture in VNS (Fig 5.4).

a b

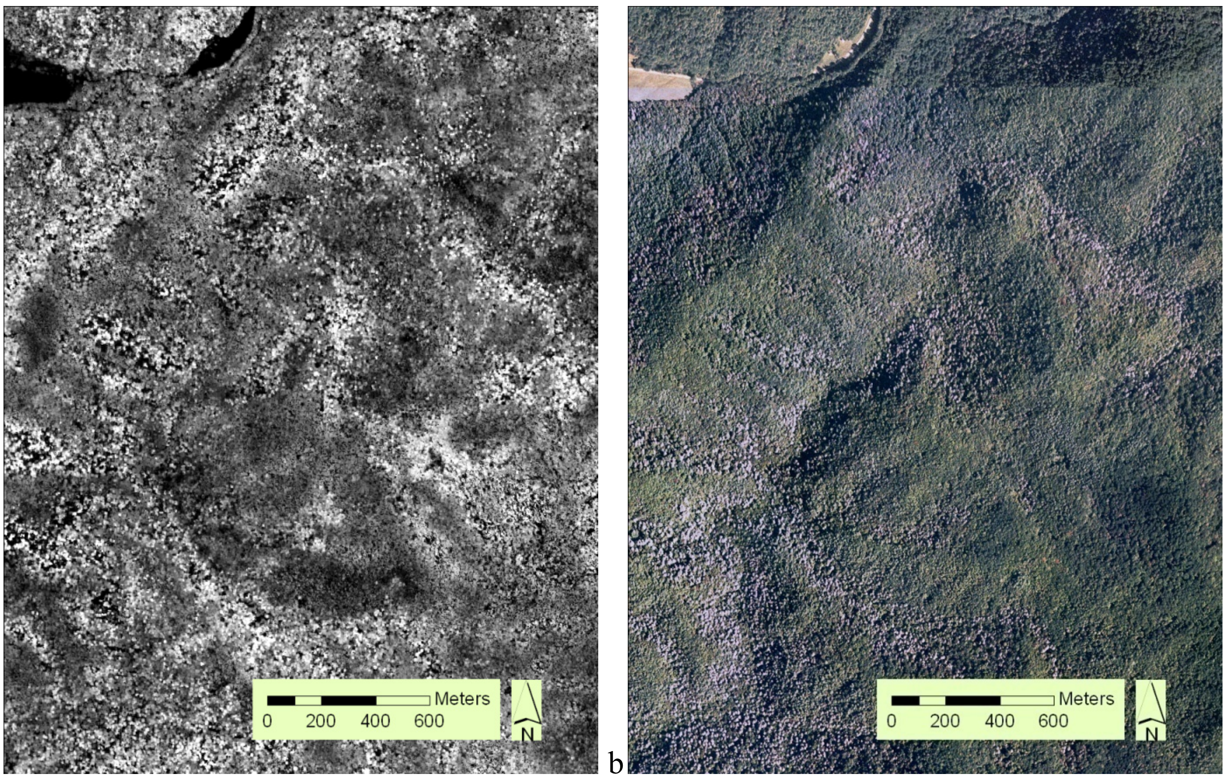


Figure 5.4 LIDAR-base DEM (a) where lighter cell values indicate higher canopy height values and black lower values (range was 8 to 153 feet excluding outliers), and (b) NAIP image for reference.

This texture was georeferenced and linked to the virtual ecotypes thus providing spatially referenced values that constrained the heights of individual tree objects placed on the individual 3 meter cells.

The virtual ecotypes are components in VNS that allow the producer to link database domains with other components and textures. In the case of the canopy DEM, the grid was linked to the height value in the ecotype component as an image texture. Rather than use absolute tree heights, VNS allows for a percent of a set maximum height or a range of height values. Since the maximum height stated in the NatureServe plot for a hemlock polygon was 50 meters, the values of the LIDAR-based canopy height grid would vary that maximum height based on the distribution of values in the canopy DEM. The highest value cells of the grid (displayed as white) do not constrain the maximum value and lower value cells (gray and black in the grid) constrain the maximum height value, thus generating variability that is based on a spatially referenced image texture.

The integration of data sets into the VNS framework allows for raster images and vector data to drive the placement of vegetation objects and textures on the terrain. The aggregated, vector-based vegetation data set from CRMS-NPS depicting pre-HWA invasion conditions and a classified hemlock dieback raster dataset derived from the 2006 NAIP image were both subset for efficiency purposes and integrated into VNS. These two derived data sets were used in VNS as the basis for the development of virtual ecosystems. In VNS, both vector and raster models can be linked to either a 2D billboard image object (in the case of stand-level renderings), or (in the case of plot-level renderings) to 3D object files imported into VNS from Xfrog (Fig 5.5). So tree species, for instance, either as 2D image objects or 3D image objects can be linked to the virtual ecotype and distributed on the landscape using georeferenced grids or vectors. The field data were assembled as a point-based shapefile in ArcGIS and were used only for placing the 3D object vegetation models (Fig 5.5).

As previously mentioned, in VNS, "virtual" ecotypes may be placed within vector model geometries and tied to relational databases that allow for attributes to be queried and linked to the ecotypes. These ecotypes are organizational features in VNS which allow specific combinations of individual vegetation objects to be rendered based on the spatial profiles of either a polygon data set (e.g., the CRMS-NPS vegetation data set) or the raster cells of a classified data set known in VNS as a "color map". As mentioned before, the GRSM vegetation database produced by CRMS provides the parameters of community types at the alliance-level for the vector-based model and the details of the species composition and densities for these alliances were derived from the NatureServe plot database. Shapefiles were thus imported and utilized in VNS when visualizing the plot-level and stand-level (i.e., on the ground and just above the canopy) (Fig 5.5).

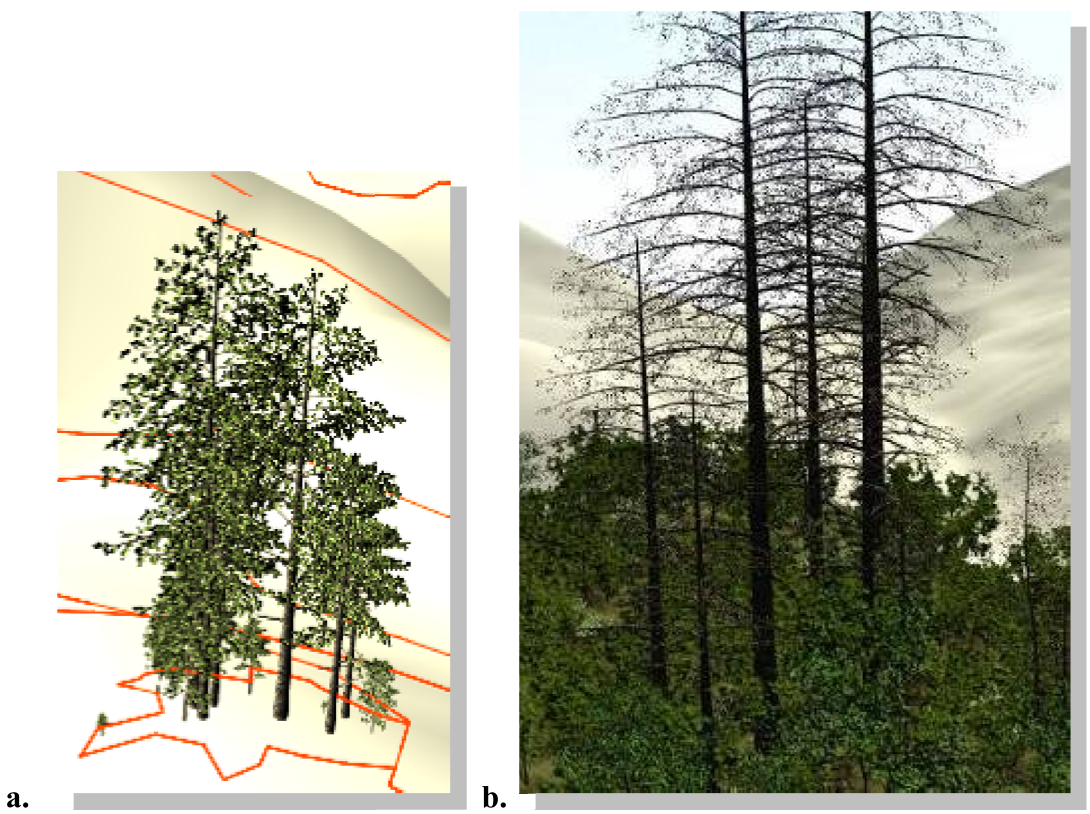


Figure 5.5 (a) The polygon data set for GRSM vegetation overlie the DEM in VNS and point data here are used to place 2D-billboard tree models in those vegetation polygons. Output from

Xfrog is integrated into a VNS rendering utilizing GIS polygons for placement and drivers of ecosystem parameters such as stand density and overstory and understory composition; (b) Point data are used to place 3D models of trees on the surface and CRMS-NPS polygons are used to drive the placement, size and density of the understory.

A 2006 NAIP image was used in the VNS "color map" method to determine virtual placement of dead hemlock in the landscape. The digital numbers of each pixel were used to classify the image and identify areas of dead and stressed hemlock (Fig 5.6). The same ecotypes that were used in the CRMS-NPS polygon data set are linked to the grid cells of the classified raster data model. For this work, the 2006 NAIP image was classified using a simple binary classification with either live or dead pixel values identified (Fig 5.6). This was accomplished using supervised classification techniques found in ERDAS Imagine. The 2D vegetation objects were then loaded and placed based on the spatial framework of the pattern established from the binary classified image.

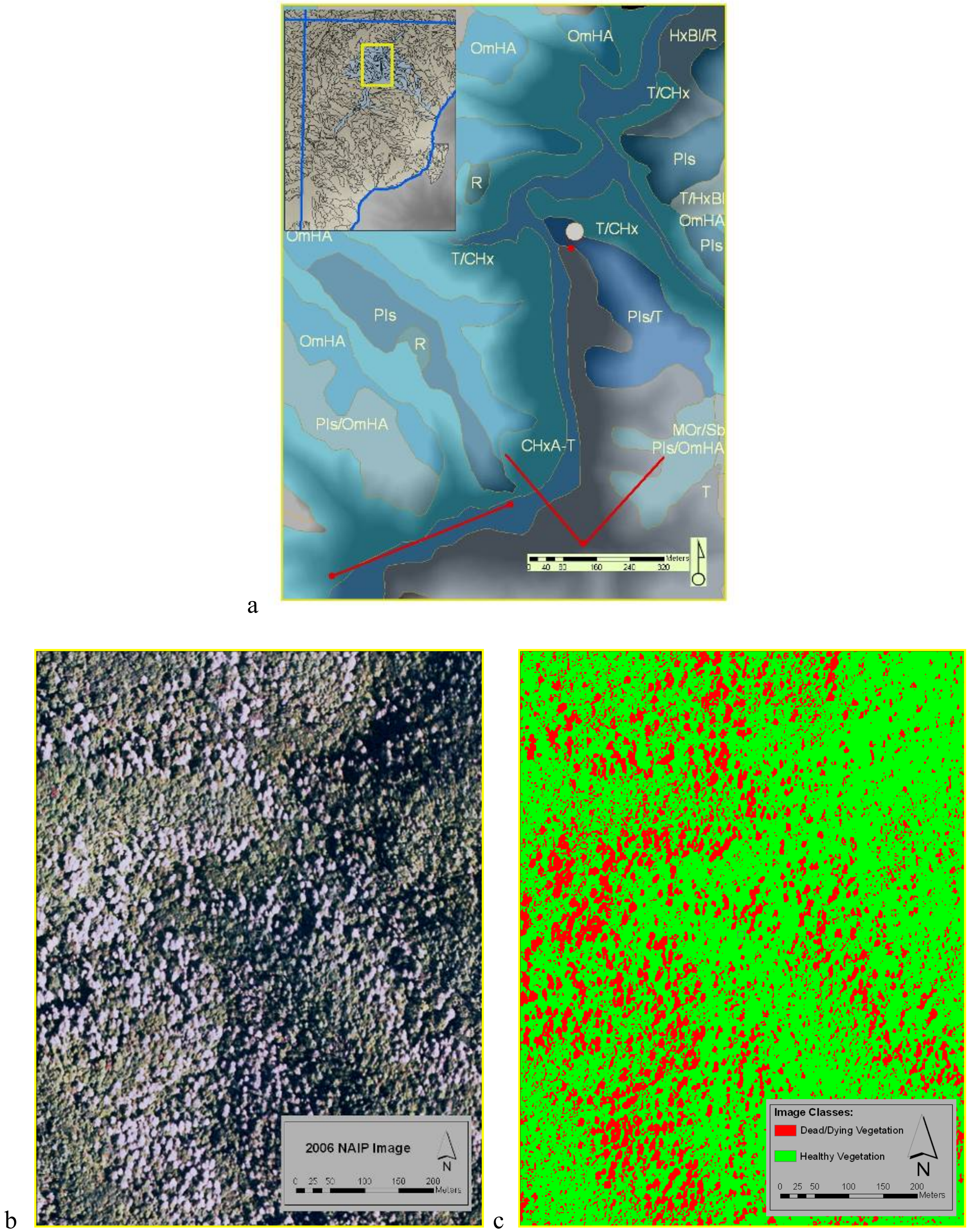


Figure 5.6 (a) Subset of the vector based CRMS-NPS database with dominant vegetation attributes labled; (b) a subset of the 2006 NAIP; and (c) classified images of dead hemlock.

For the 2D billboard images of hemlock objects used at the landscape and stand scales, four images of a hemlock tree were generated using VNS (Fig 5.7). A single model simply had four different hemlock needle images in various stages of decline used as leaf components in VNS. These needle images were rendered, edited, and imported back into VNS as image objects or billboards. The same technique was used at the plot-level except there was no need to render the image objects. Rather, the needle sequences were used directly with the 3D vegetation objects (Fig 5.8). The needle sequence was edited using Adobe Photoshop to depict increasing damage by HWA. Despite the lack of quantitative information about the levels of dieback for this study, these images could be easily linked and used as proxies until actual dieback is determined later by more extensive classification techniques.

Figure 5.7 Utilizing a single tree model inported into VNS, four different stages of dieback were generated by changing the leaf component of the model, which in this case was the needle image in Figure 10. These images were then dissolved so that as time in the animation progressed the images would fade in and out generating a linear sequence of dieback from healthy to dead.

Figure 5.8 The needle image was edited in Adobe Photoshop to uniformly represent four different stages of dieback. These techniques could be used again later with output from image classification and laboratory analysis that may offer a more detailed description of the temporal change of the dieback.

<u>Efficient use of Details and Data Representation to Create Renderings</u>

The VNS algorithms and protocol for rendering ecotypes allow producers the choice to create: 1) stylized, ideal and/or conceptual landscapes; or 2) landscapes rendered as closely as possible to reality in terms of plant species composition, terrain, plant densities, relative heights, lighting, atmospheres, and shadows. In this study, capturing the reality of hemlock communities in GRSM while creating effective, interesting and clear visualizations required the selective use of field-based information on plant densities matched with computer graphic enhancement capabilities of VNS to emphasize the important characteristics of the ecotypes.

For example, the placement of tree and shrub billboard objects at the stand-level was accomplished by using the percent cover of species recorded for the various strata (T2, T3, or S1) in the NatureServe database along with multipliers (usually 3 times or 4 times the % cover found in the NatureServe database). A different approach used the sample data from the field (i.e., stems per unit area) to extrapolate relative species densities and apply these proportions to the densities of objects placed in CRMS-NPS vegetation polygons to make the virtual environment best emulate reality (and the data). This may seem to allow for excessive "artistic license", but the creators of visualizations must make decisions on VNS data inputs that determine the level of detail that can be discerned with this type of virtual environment. The rendering approach in this study aimed to represent the species mix and density at each scale to describe the overall effects of hemlock dieback. Most important here in terms of ethics is the transparency of these methods so that users of these visualizations fully understand the procedures for generating them and the goals of the visualization are clearly stated (Sheppard 2001).

Once all ecotypes are linked to the appropriate attributed polygons, points, or grid cells, the next step involves a trial-and-error method of getting the various data to “look” like the real environment, as well as describe the data in the most clear and accurate manner possible. There are tools in VNS to help with this procedure. The forestry wizard, for example, can utilize standard forest metrics such as percent cover or stems per unit area and diameter at breast height to facilitate the translation of forest stand GIS databases and field-based measurements into rendered visualization output.

Keeping in mind renderings created in VNS must employ the most appropriate and efficient levels of detail from available datasets, individual species were not used to represent hemlock communities at the landscape-level. Instead details at the landscape scale included delineations of dead vegetation and general vegetation types such as evergreen and deciduous trees. The stand-level included mainly the T2 and T3 strata since views of this scale do not give details of the understory beyond the general color and texture of the shrubs. The plot-level is the appropriate scale to represent the understory data effectively. At the plot-level, the output included representations of the canopy, sub canopy (T2 and T3 of the NatureServe data, respectively) and the first shrub layer (S1).

Cameras Views

Camera position is another important consideration in a visualization environment. Decisions must be made about generating believable or familiar perspectives and, if movement is used, whether an animation may contribute to the visualization goals or be more distracting than informative. The position of the camera establishes the viewing angle and determines the scale for the rendering. The angle of view and the position of the camera will affect how the results will impact the viewer, so for this work it was determined that the view should best emulate a natural field of view.

Focal length establishes the "field of view" (FOV) which defines the area of the virtual environment to be viewed. The average viewing angle of the human eye is between 45 and 47 degrees, which correspond to a focal length of 40-50 mm (Mach and Petschek 2007). Too wide or narrow a FOV will produce a view that may distract from the scene with either too much information or an unrealistic perspective. Also, distortion is inevitable at the wider angle FOV's, or shorter focal length, while with a longer focal length and narrow FOV, there is a lack of perspective and depth (Mach and Petschek 2007). The camera position and FOV in all renderings for GRSM at the stand and plot-levels were chosen to best represent a realistic view one would find in the park either from a clearing on a ridge or from the ground. At the regional and landscape scales, the camera position was set high above the terrain and moved to depict broad scale patterns and extent of dead hemlock trees found in the Cataloochee Valley of GRSM.

In addition to the animation, fixed perspectives were utilized at the plot and stand-level as a way of viewing the temporal change of vegetation dieback. When the position of the camera is fixed, a higher level of detail and more information can be distinguished such as vegetation associations, compositions and densities at the stand scale and light penetration, individual plants in forest strata and shadows at the plot scale. Moving away from the canopy to the landscape scale, less detail of the different tree species and strata are available and the general pattern of the live or dead foliage becomes the most important and efficient information to portray. At this scale the camera movement is less of a distraction and, again provides a greater spatial coverage of the data. Accentuating the appropriate detail of information in data sets and utilizing these patterns to describe these data is not only beneficial to the effectiveness of any visualization, but it also is imperative to the efficient rendering and organization of large visualization projects.

CHAPTER VI

RESULTS AND DISCUSSION

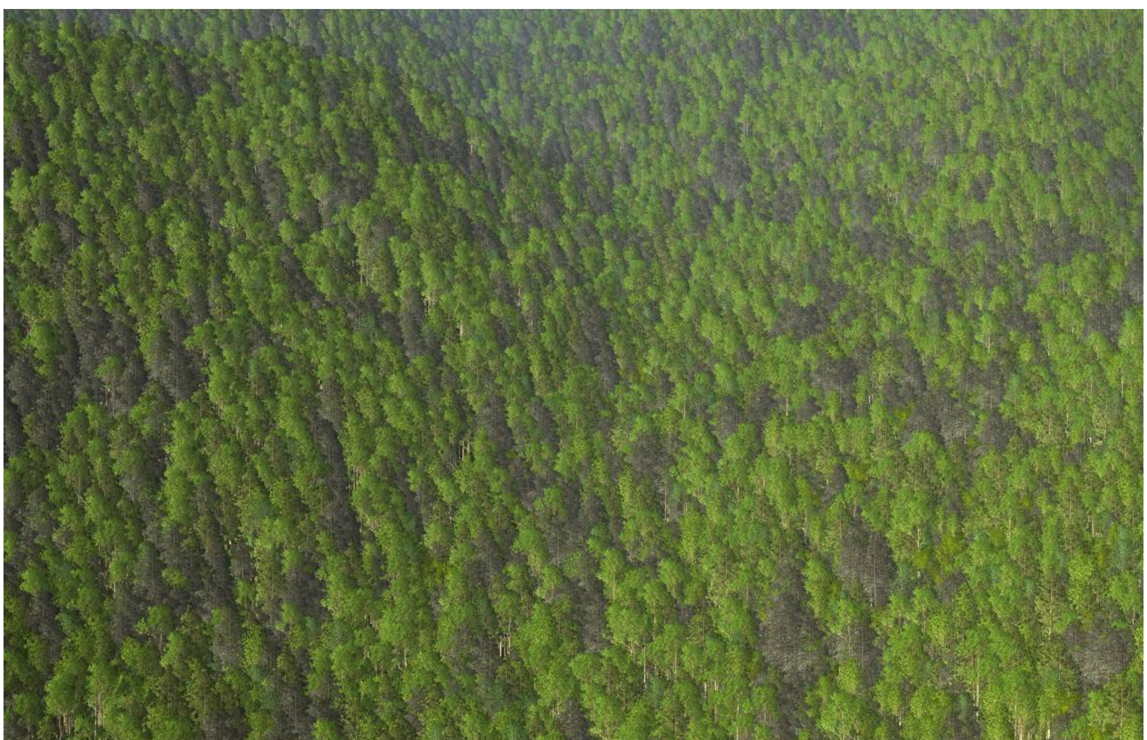
Results of this study featured the creation of geovisualizations depicting hemlock dieback at various scales. A broad-scale regional flythrough incorporated several data sets including 2008 LANDSAT satellite imagery, a 2006 NAIP air photo and a classified derivative of the NAIP imagery of hemlock dieback. This flythrough animation provided an overview of the region and guided the viewer down to landscape-scale patterns of dieback within hemlock forest communities in the Cataloochee Valley of GRSM. The landscape-scale visualization used exclusively the classified 2006 NAIP imagery of hemlock dieback and focused on patterns at a larger scale utilizing 2D billboard tree objects. At this level generalization was maintained to allow movement of the camera without distracting from any details depicted in the views. At the stand-level, the rendered output was from a fixed camera position and used the more detailed vector data from CRMS-NPS vegetation data base to create an animated sequence of images that more clearly represents four stages of hemlock dieback in GRSM, namely healthy, infested, dying, and dead trees. The plot-level results, also with a fixed camera position, provide highly detailed renderings of 3D vegetation objects allowing for an immersive detailed view of individual tree positions, densities and heights. The plot-level also included 3D shrub strata vegetation, with relative strata heights and densities found in the understory. In addition, the plot-level renderings, utilizing features found with 3D models of plants, were able to generate a temporal sequence in the light conditions (due to the loss of large canopy hemlock trees). The temporal sequence of hemlock dieback depicted within all these results were based on change documented between the pre-HWA invasion 1997-1998 CIR air photo based CRMS-NPS database and the post-HWA invasion 2006 NAIP image, thus representing a transition from healthy to dead conditions in roughly 9 years. Although the animation shows a steady and gradual dieback, park managers, in fact, did not report any sign of HWA infestation until 2003. This raises the point of how quickly (roughly 3 years) in this particular environment the infestation spread and consequently wiped out this major tree species.

Landscape-Level Output

Landscape-level renderings (Fig 6.1) successfully portrayed the patterns of hemlock dieback found in the 2006 NAIP image. These views offer insight into smaller scale patterns of dieback that correspond to landscape scale processes. Vegetation associations, although not explicitly represented at this scale, do play an important role in the patterns of represented dieback. The patchy distribution of the patterns generally describes the mix of other association and tree/shrub species relative to positions in the terrain. Also, the scales of the views provide immersive aspects with elements such as topography, atmospheric haze and decreasing level of details of trees in the foreground to the background in an effective and efficient way. An important element of this scale is the exclusive use of publicly available free data from the U.S. Department of Agriculture (National Agriculture Imagery Program-NAIP). The impression of dieback at this scale may inform viewers of the broad scope of the issue since many park visitors may only be able to glance at hemlock dieback when driving down mountain roads. The visualization also shows that the problem is not isolated in any one area of the park.

Further work at the landscape-level should incorporate information from the near infrared band of the 2003 IKONOS imagery to delineate broad-scale patterns of evergreen, deciduous, and mixed components that coincide with the output of dead foliage from the NAIP imagery. The resulting classified image would then depict the intermediate stage of patches and patterns of dieback mapped as dead trees in the 2006 classified NAIP image. This would offer a more accurate representation of the temporal decline of hemlock forest at this scale. In addition, hybrid techniques could be developed in VNS that use both vector-based information from the CRMS-NPS vegetation database and the raster-based information of the dieback pattern. This hybrid method may offer a more efficient way to incorporate appropriate details and best represent patterns found at multiple scales.


a


b

c

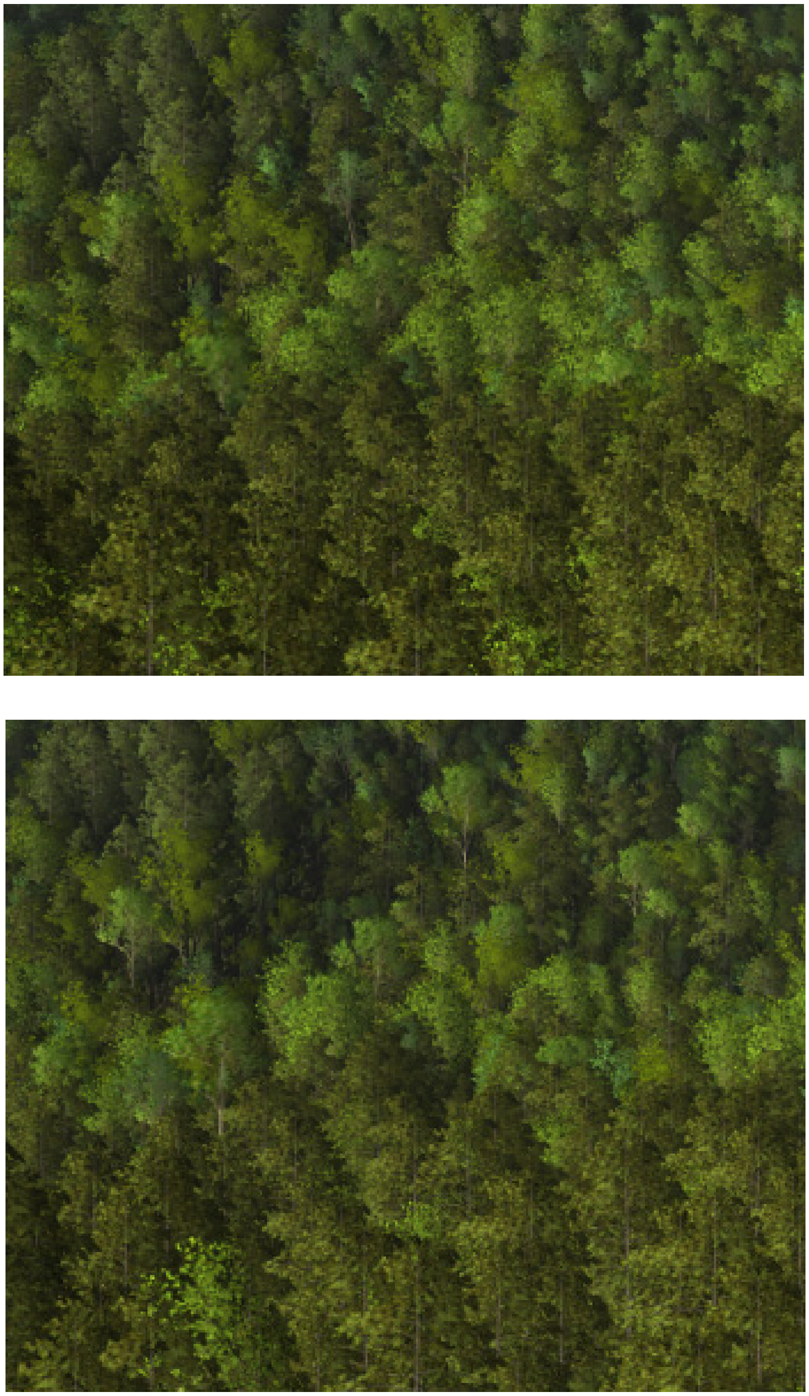
d

Figure 6.1 Rendered images (a, b, c, d) represent the landscape scale dieback patterns of hemlock from HWA that were produced using VNS. More variation in the live vegetation pattern could be achieved by utilizing information from IKONOS imagery obtained in 2003.

Stand-Level Output

The stand-level was determined to be the proper scale to include the LIDAR-based 3-m DEM for canopy height variation. The canopy height also may be generated with a random pattern option found in VNS. When considering how difficult it is to locate raw LIDAR data and the expense of gathering the data, the variability gained at this scale (Fig 6.2) may not be significant enough to require its use in future projects especially since random patterns may generate similar visual results at the stand scale. Other derived data sets from LIDAR-based data may include stand density or details on forest structure. These derivatives could, when available, provide some valuable information for detailed physiological and ecological conditions, as well as validation of the rendered results.

Results presented in (Fig 6.3) only include LIDAR data for canopy height variation and vegetation details are derived from the CRMS-NPS vegetation database. These results show explicit details of the vegetation associations found in the CRMS-NPS database and also allow for individual species to be discerned, especially in the foreground of the images. The details of the hemlock dieback are clearly depicted showing how a stand of individual hemlock trees impact the structure of the canopy and the surrounding forest strata. Rendering the T3 and S1 strata only in the foreground limits the details to the position of the camera, providing important information discernable at this scale, but does not use up any more computational resources than needed. This scale, though, only provides these strata with limited detail and is used mainly to visually present the stand as it would look in reality.



a

b

Figure 6.2 A comparison of a stand scale rendering without variability from LIDAR data (a), and variability based on canopy height data from the first and last returns of original raw LIDAR data (b). Note shadows in background as well as hemlock trees in the foreground.

a

b

c

d

Figure 6.3 These renderings (a, b, c and d) represent the stand scale dieback patterns of hemlock from HWA that were produced using VNS.

Plot-Level Output

The plot-level renderings effectively convey the detailed structure of the various forest strata including the canopy, sub-canopy and major understory shrubs. This scale brings a unique perspective typical to a GIS flythrough by allowing viewers to see photo realistic views of the terrain, details of individual species with unique branching structures and architecture, leaf shape and color variations. The realistic spacing of trees is based on GPS locations of actual trees at that particular stand in the field and the sizes of the trees are based on measured dbh. This scale provides an interesting virtual environment grounded in field measurements that emulates what would be experienced standing within the actual plot in the field.

Results found in Figure 6.4 do not provide evidence of shadow updates due to the position of the sun which is georeferenced and based on a specific date and time of day. The sun component in VNS provides mainly a seasonal and/or diurnal simulation of the sun's position, but it emulates lighting conditions accurately for the virtual environment. The lack of surrounding foliage and contextual scenery at this level was a conscious decision to simplify the scene due to the complexity of vegetation. Preliminary plot-level views caused focus to be quickly lost and attention to stray from specifics of the ground-based data including sizes and distribution of plant species at this sampled plot. Continued work with generalization of distant plant elements and refinement of camera location, though, may allow for the views at this scale to also contain elements from both the stand and landscape scale renderings, thereby providing a closer representation to the real world scene.

It is well known that shadows generally help to establish the 3D aspect of objects in space making for a realistic simulation. Yet, with these results the shadow detail was refined to the level where the results depict the changing light from needle loss of the hemlock trees. The


a


b

c

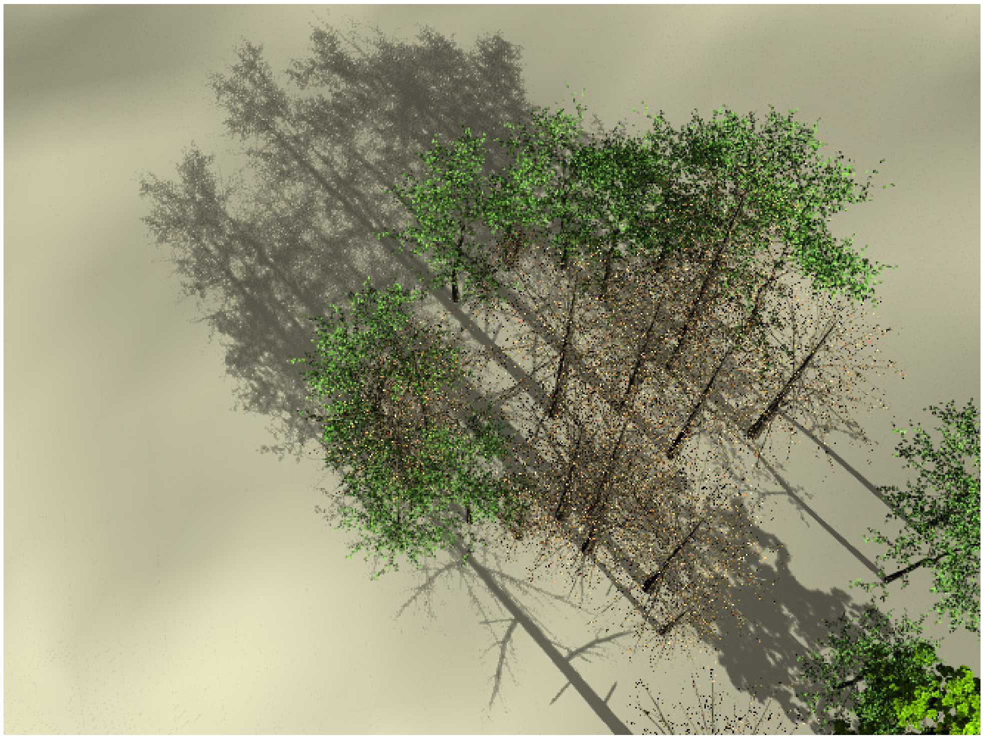
d

Figure 6.4 These renderings (a,b,c,d) represent the stand plot-level dieback of hemlock from HWA.

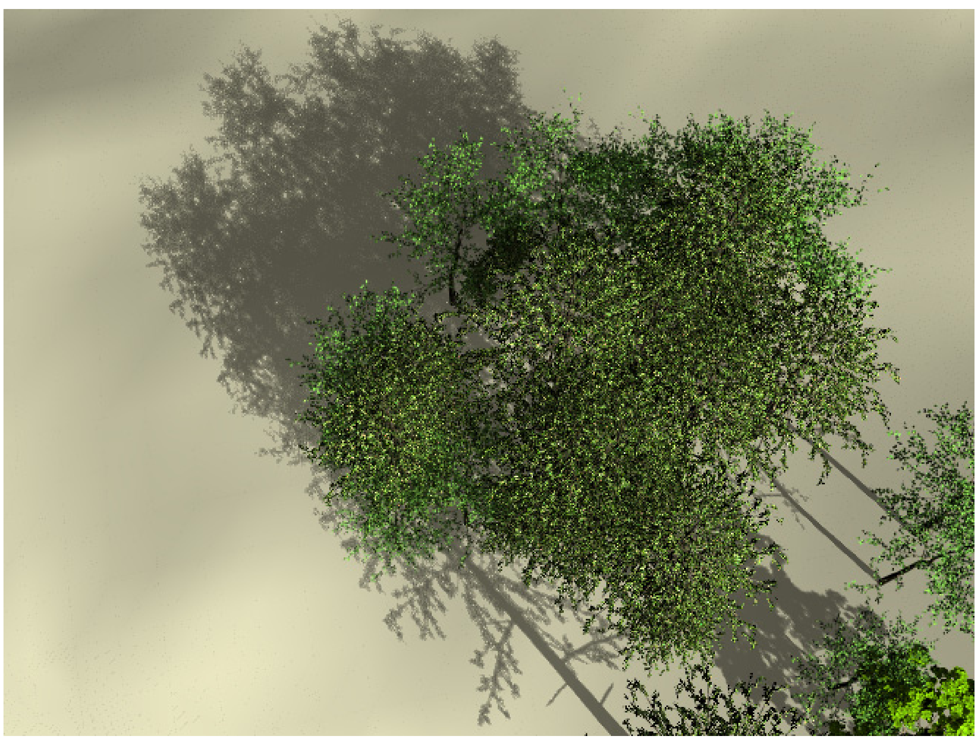
effective use of shadows (Fig 6.5) also provides the needed details of spatial and lighting changes at these more refined scales. Details of the herbaceous layer could be included in a view that focused less on the canopy structure and more on the shrub/herbaceous layers. This would be beneficial in future scenarios when envisioning the new growth and changes that occur as light and moisture levels change due to the hemlock in the canopy dying. This is a truly unique result that can be utilized when modeling or simulating specific microclimatic changes in any ecological disturbance scenario.

By utilizing, or accentuating, the patterns at each scale of the dieback, the visualizations produced here aim to enhance scale-dependent information to highlight particular aspects of the hemlock dieback and feature information based on GIS vector and image data sources. The understanding of available parameters and capabilities of the visualization platform (i.e., VNS and Xfrog in this study) should ultimately allow for the proper design and building of geospatial databases best suited for these types of visualization techniques. As mentioned previously, creating a scene that visually approximates the actual environment, but also accurately represents the image, GIS, and field data, is difficult to accomplish. Clear documentation of the process is important to give the users a better understanding of the empirical and scientific work behind the rendered output. It also increases the transparency of the work and ultimately builds a more solid framework for these methods to be used in the future.

The versatility found in VNS requires the user to understand characteristics of the input data relative to the goals of the geovisualization. What may seem like a complex and difficult software for unskilled operators is really a powerful geospatial tool that can integrate many different data types and themes to create novel and informative visualizations. Generalization of details contained in images and GIS vector databases may be necessary to balance appropriate



a



b

Figure 6.5 (a) Before and (b) after comparison that focuses on the details of the shadows provided by using 3D models and image textures with appropriate alpha channels. The alpha channel allows for the light to pass through, so modifying alpha channels based on the dieback sequence provides a realistic shadow.

level of detail with the scale of observation. For example, a specific ontology may need to be modified or a large domain may need to be simplified in order to clearly depict landscape features of interest. By not posing limitations on data input and allowing the producer to select the level of detail, VNS ultimately provides accessibility to multi-scale data, flexibility and powerful visualization potential. Data acquisition, storage and availability are not based on any software, especially visualization parameters, since any one data set may have value to a myriad of different studies and needs. The automation of data integration in VNS may provide a greater quantity of output, but the quality of the results requires careful oversight by the producer. Indeed, the producers of visualizations must have a solid understanding of the data sources and the goals of the visualization to best convey and communicate both empirical data and qualitative environmental elements (Gardiner 2007).

Limitations found in VNS based on the methods presented here include the lack of immediate control over cartographic elements in the final rendered views. Only views with a zero degree pitch angle can be used in post processing in VNS to include automatic directional referencing and the display of headings in each rendered scene. This heading is updated continuously in the post processing and will automatically adjust to the camera's movement in an animation. It provides a very efficient and effective way to provide simple directional referencing for users of the visualization, but is unfortunately limited in scope. As an alternative, the post processing components in VNS do support the addition of text that would allow some additional information to be rendered with each frame, As such, a text-based description may be used to give the user a heading, but in an animation sequence, each image rendered from a new direction would then need to be updated with new text in the post processing. This would require additional work from the producer that should be otherwise accomplished automatically with the inclusion of a north arrow or the heading indicator mentioned previously. Reference maps that denote location and camera viewshed from an orthogonal position also may help to orient the user. These limitations are minor and with continued use of the software undoubtedly can be "worked around" with successful results.

CHAPTER VII

SUMMARY AND CONCLUSIONS

The integration of multiscale image, GIS vector and field data can be successfully performed within the GIS visualization platform, Visual Nature Studio (VNS), to create photorealistic representations of vegetation dynamics within hemlock dominated stands of Great Smoky Mountains National Park (GRSM) impacted by invasion of the exotic hemlock woolly adelgid (HWA). Field studies and photo documentation of hemlock communities were used to build texture and structural databases that, in turn, were input into Xfrog software to model 3D individual tree and shrub species found in hemlock communities. Three different resolution DEMs (3-meter, 10-meter and 30-meter) from the National Elevation Dataset (NED) were utilized to provide the basis of the virtual landscape with efficient details of topography from the regional to plot-levels and provide surface constraints on vegetation placement.

Vegetation was placed in the virtual landscape according to NatureServe data sets describing percent distributions and linked to both raster and vector-based geospatial datasets for accurate spatial distribution. Geovisualizations of vegetation associations from the existing vegetation databases and ground information resulted in stand and ground-level renderings with details of species compositions and 3D spatial position and lighting characteristics. Classification and analysis of 2006 NAIP imagery provided information of hemlock dieback necessary for descriptive characterization of disturbance by HWA at the landscape scale. The final renderings and animations from multiple scales document changes in hemlock and adjacent vegetation communities at four stages of decline between 1997 and 2006. The results may be incorporated with standard 2D maps and graphics or as 3D animations and other geovisualization applications to depict the impacts of hemlock dieback to diverse audiences.

In regards to the objectives of this study, all goals were met, yet some objectives deserve further attention and have been addressed as potential future work. Specifically, the first objective was aimed at the development of a vegetation library that would serve as the basis for 2D and 3D plant objects used in the visualizations. The colloquial aspects of the models to match that of the unique vegetation found at the study site in GRSM was accomplished using the interactive tools of Xfrog modeling software, and these models can serve as templates for future work. Simple modifications to fit other specific physiological and architectural characteristics of other sites would be straightforward and efficient to perform.

The second objective was to establish methods that demonstrate that these techniques can be used effectively with disparate geospatial data sets not only for this project but for future projects as well. Considering that this project has produced suitable results in a reasonable timeframe demonstrates the potential for these geovisualization techniques to be used in the future. These methods and the results presented here document positive aspects and also the pitfalls to generating virtual environments.

The third and fourth objectives were based on providing an integrated visual representation of data from different scales and to engage viewers by highlighting domains of those scale specific data. VNS offers flexibility for the integration of various vector and raster-based GIS datasets along with the power of relational databases to link specific domains of data sets to realistic graphic media components. The results of this work provide a methodology to integrate engaging graphic media with these explicitly referenced GIS data that meets the demands for generating interest from people with various training and background. Further work could be done to document the responses of various user types and refine the results of visualizations like those presented here to the specific needs of different users.

The demand for science-based geovisualizations has grown in light of the complex relationships and communication needs of various organizations that often collaborate on major research projects and environmental management proposals. Within this context of integrative research, Fray et al. (2007) have discussed the need for ways to efficiently bring disparate view points from different knowledge bases into a cooperative framework that will ultimately help members of large projects operate effectively. A motivation of integrative research is increasing interaction of society and science, and their liaison with public policy is becoming more and more common. Thus, researchers are expected to contribute to problem solving with the capability to examine issues from multiple perspectives (Fray et al. 2007). Many of the problems associated with the integrated approach stem from organizational and communication barriers. Also, there is often a clear disconnect between the theoretical knowledge base for different research departments and the scope of various agencies. A good example is the oftentimes conflicting views of developers, environmental groups and resource managers who all may be interested in approaching policy decisions from very different perspectives. The geovisualization methods described here provide examples of ways to break through communication barriers between disparate perspectives found in academia and those especially found in the dialogues between academia, policy, and the lay community.

For some, the colors, textures and emotive responses associated with photorealistic visualizations are considered "fluffy" in terms of applicability to solving major environmental problems. This, however, exemplifies the problem that many disciplines face when cooperating on large research projects. There is no reason to make a hydrologic engineer's tool set merge with that of an environmental historian. There is good reason, though, to provide interfaces and geovisualization products that will allow for better communication and exploration of the data that, ultimately, these researchers are all working with to provide solutions to major problems. Many now do conclude that there is value to visualization that provides opportunities for viewers to virtually "experience" the outcomes of planning scenarios or model projections. There also is worthy attention being paid to the emotional response evoked by photorealistic views which brings a quicker cognition and substantive interaction to our relationship with environmental data.

Referring back to the research agenda proposed by the UCGIS, there is a need to better engage people with geospatial data that emulate our immediate experiences of the real world. There are limitations, however, to what perspective any one single data source can offer, not only in the explicit limits of the instrument but also in the way that the data are referenced. Thus, there is a need for effective data integration of multiple geodatabases and visual analysis capabilities in order to reconstruct complex environmental scenarios that make use of data-rich repositories of satellite images, scanned historic air photos, GIS vector data, DEMs, ground photos and other field data.

The traditional dichotomy between cartographic communication versus spatial data exploration is a good way to maintain divergent opinions and to keep people using either an aesthetic or logical approach to interacting and assessing geospatial data. This arbitrary divide does not have to continue since technology now offers ways to blend high-level graphic media with large geospatial data sets within a simple PC environment. Today, the available technology provides remote sensing data that far exceeds anything we will be able to sense on our own. It is then necessary to gather the disparaged domains of geo-information back into the context that is closer to the real world. The representations available in virtual environments and renderings such as those demonstrated in this work are still a far cry from representing the complexity of the real world. However, the geovisualization tools that are now available make the rift between communicating and exploring geospatial data much smaller by offering efficient and, engaging digital representations of the real world.

At the most basic level, this study documented the methodology of utilizing photorealistic geovisualization techniques to describe ecological change in a forested landscape. Issues that deserve further attention include better understanding the responses of individuals to different photorealistic techniques. This would require a survey of various users, data types and statistical analyses to link viewer responses to various visualization scenarios and methodologies in order to identify specific and effective approaches to provide representations of geospatial data to particular viewers. This will help ensure these techniques are readily available and efficient for others to use. Also, future work should include performing further, extensive, image analysis and classification procedures and modeling techniques to investigate spatio-temporal variability of major ecological disturbances such as HWA and implications of future of vegetation changes in conservation areas. Both spatial and temporal elements should be refined to better represent spatio-temporal variability both in derived data from analysis and visualization of these derived data.

A theme of this study was accessibility and a next step for future work is providing geovirtual environments, such as those presented in this work, on the World Wide Web. The internet is, for most, the best route for disseminating geospatial data sets and information. One of the issues presented with this study is the compromise between high levels of realism and high levels of interaction. Web-based dissemination of geovisualizations require the utmost efficiency of various components and geometries so that, not only can the results be offered to users across the web, but also to ultimately allow viewers to have interaction in these types of virtual environments. The Nature View component of VNS is a proprietary-based extension of VNS that will export an entire virtual landscape into a "nature view" format. This allows for their real-time 3D viewer (a free and fully executable file that does not need to be installed on users machines) to open the exported file and offer user interaction with the landscape. The virtual landscape can also be exported into Google Earth formats (.kmz and .kml) or a generic VRML (virtual reality modeling language) format. This provides immense access to these types of visualizations in a format and interface that nearly anyone who has used Google Maps or Google Earth would be comfortable working with. In addition, the proprietary format (Nature View) also provides for hyperlinks so that objects in the scene provide specific data, tables, charts, photos or other links that provide a truly exploratory environment.

The legacy of graphic products and technological development mentioned in this work is a testament to the direction in which interfaces of geospatial data are heading. More research is needed to continue expanding geospatial mapping procedures to include geovisualization methods so there is a continued refinement of the elements and improved organization of the various components of a virtual environment. This will help to ensure that data with differing ontology and users with different perspectives can integrate in an engaging and effective virtual space. These approaches to data geovisualization for analysis and communication will bring a more engaging and comprehensive framework for many people and allow them to efficiently and effectively depict complex data in order to solve complex environmental problems.

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