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Three Dimensional Visualization of Fire Spreading Over Forest Landscapes

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THREE DIMENSIONAL VISUALIZATION OF FIRE SPREADING OVER FOREST LANDSCAPES

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ABSTRACT

Previous studies in fire visualization have required high end computer hardware and specialized technical skills. This study demonstrated fire visualization is possible using Visual Nature Studio and standard computer hardware. Elevation and vegetation data were used to create a representation of the New Jersey pine barren environment and a forest compartment within Hobcaw Barony. Photographic images were edited to use as image object models for forest vegetation. The FARSITE fire behavioral model was used to model a fire typical of that area. Output from FARSITE was used to visualize the fire with tree models edited to simulate burning and flame models. Both static and animated views of the fire spread and effects were visualized. The two visualization methods were compared for advantages and disadvantages. VNS visualizations were more realistic, including many effects such as ground textures, lighting, user made models, and atmospheric effects. However the program had higher hardware requirements and sometimes rendered images slowly. ArcScene had lower hardware requirements and produced visualizations with real time movement. The resulting images lacked many of the effects found in VNS and were more simplistic looking.

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TABLE OF CONTENTS

Page

TITLE PAGE i

ABSTRACT ii

ACKNOWLEDGMENTS iii

LIST OF TABLES vi

LIST OF FIGURES vii

CHAPTER

I. INTRODUCTION 1

Landscape Visualization Software 3
Study Goals 9

II. VISUALIZATION USING VISUAL NATURE STUDIO 12

New Jersey Pine Barrens 12
Visual Nature Studio Visualization Methods 15

III. VISUALIZATION USING ARCSCENE 28

Hobcaw Barony 28
ArcScene Visualization Methods 30

IV. RESULTS AND DISCUSSION 36

Data Compatibility 42
Visual Nature Studio: Strengths and Weaknesses 43
ArcScene: Strengths and Weaknesses 47

V. CONCLUSION 50

Table of Contents (Continued)

Page

Future Wildfire Fire Visualization Research 53

REFERENCES 56

LIST OF TABLES

Table Page

1.1 Visual Nature Studio and ArcScene comparison..52

LIST OF FIGURES

Figure Page

1.1 Examples of MONSU visualizations 5

1.2 Examples of Smart Forest visualizations 6

1.3 Examples of FORSI visualizations 7

2.1 VNS visualization of pine barrens before fire 17

2.2 Canopy Bulk Density map 19

2.3 Example of RGB color matching in VNS 20

2.4 Example of FARSITE output 23

2.5 Example of individual flame and tree models 24

2.6 Additional flame and tree models 25

3.1 Tree canopy positions of conifers in Hobcaw 4 32

3.2 Tree canopy positions of hardwoods and fire spread 33

4.1 Example of ArcScene visualization 37

4.2 Example of animated VNS visualization 38

4.3 Example of VNS visualization showing fire spread 39

4.4 Example of VNS visualization showing burn severity 40

CHAPTER ONE

INTRODUCTION

Visualization is defined as any technique for creating images, diagrams, or animations in order to convey a message. Advances in computer hardware and software over the past 30 years have allowed researchers to simulate and visualize complex forms, phenomena, and dynamics in natural systems such as plant growth or changes in atmospheric conditions (Ervin and Hasbrouck, 1999). Visualizations which previously required specialized computer systems and hardware can now be done on more affordable desktop/laptop systems. With this increased accessibility, visualization has become a tool available to even more researchers as a means of analyzing data.

In the field of landscape management and forestry, visualization can be used to demonstrate and analyze data from geographic information system (GIS) or remotely sensed systems such as aerial photographs or satellite images. Through the commercialization of hybrid 2D/3D visualization software such as Bryce 3D (DAZ Productions), World Construction Set and Visual Nature Studio (3D Nature Inc.), and VistaPro (Virtual Reality Laboratories Inc., 1993), 3D modeling of landscapes possessing a high degree of realism, from different viewpoints, and having animation paths is now possible (McGraughey, 1998; Muhar, 2001). Due to the release of these programs, the use of visualization has become an important tool for analyzing existing forest landscape resources and for assessing the impact of proposed management practices (Lange, 1994; Orland, 1994b; McCarter, 1997; McGaughey, 1998). Furthermore, it can aid in the understanding of succession dynamics and spatial patterns within a forest ecosystem. It may also be of aid to forest managers when selecting management practices which in turn help to efficiently utilize forest resources.

With the ability to produce realistic representation of data, visualization can play an important role in the land management decision making processes. An important question that can be raised is what level of realism is necessary to draw meaningful conclusions from visualized images. Understanding how people observe and process visualizations can assist in making them better able to present data and natural phenomena.

Oh (1994) studied the effects of representational image quality on perception. In scoring of representative images ranging from a simple wire frame view to a fully digitized, color photographs, the wire frame and simple views were rated much lower. Likewise, these simpler views were also rated lower among observers having less knowledge of visualization and of the site.

Further studies by Bergen et al. (1995) compared scenic beauty ratings based on photographs to those obtained from computer generated visualizations of the same scene. Overall, the correlation for the rendered scenes and photographs were not significantly different, but the correlation for a smaller subset of five views had a higher significance where the rendered scenes played a more important role in the beauty rating. Computer rendered visualization may have played a role in the preliminary assessment of the scene, but final quality decisions were found to be best done using photographs.

Daniel and Meitner (2001) compared different levels of realism/abstraction among visualized scenes. The most realistic scenes had full 16 bit color images with each successive scene having lower realistic qualities ranging from 4 bit color to black and white sketches. Visualized scenes with the highest realism had the highest correlation with perceived beauty. Likewise, it was also found that each reduction in realistic quality resulted in a corresponding reduction in correlation with perceived beauty.

The processes identified in these studies play a crucial role in making useful visualized scenes. Moreover, software applications used for visualization must take these processes into account in order to be effective.

Landscape Visualization Software

There are several different applications for landscape visualization such as Bryce 3D and VistaPro. However, each of these software packages is written with different goals in mind and each one can have different advantages over the other. In a comparative study, Karjalaimen and Tyrväimen (2002) evaluated the three applications of MONSU (Pukkala, 1998), Smart Forest (Orland, 1994a), and FORSI (Plustech Ltd.) for their ease and suitability for producing landscape visualizations.

MONSU (Figure 1.1) produces automated computer line drawings based on site and tree parameters, rendering trees accurately in both size and shape as 2D or 3D images. However, understory elements are not present and ground elements are drawn as different colors. Landscape elements such as bushes, uniquely shaped trees, and buildings are not present either. The lack of these features being rendered makes MONSU a poor choice for visualizing landscapes with special scenic beauty. The application's main strength comes from the ability to use forest inventory data very efficiently, being compatible with available forest inventory and satellite data. MONSU can simulate movement through a visualized forest by drawing scenes from points along a selected path; however, at the time of publication, real time movement was not possible due to hardware constraints.

Smart Forest (Figure 1.2) is an interactive, 3D software package that has a management and landscape mode. Management mode provides a simplified view of the forest for quick queries of individual trees and forest stands in order to analyze the data. Landscape mode renders much more detailed and realistic scenes, with trees and water being presented as texture mapped objects and ground details wrapped with 2D images generated from digitized photos. Smart Forest also allows user defined heights to view scenes at different levels and movement within the scene for a real time walkthrough of a virtual forest. However, the application optimizes graphic quality in order to produce smooth moving walkthrough animation. Due to these optimizations, the ability to accurately represent local forest scenes when using Smart Forest's real time movement is greatly reduced.

FORSI (Figure 1.3) is a smaller landscape visualization application designed mainly for Finnish organizations, however, it was written for realism and flexibility. Forest elements are represented by 2D objects which are generated from digitized photos.

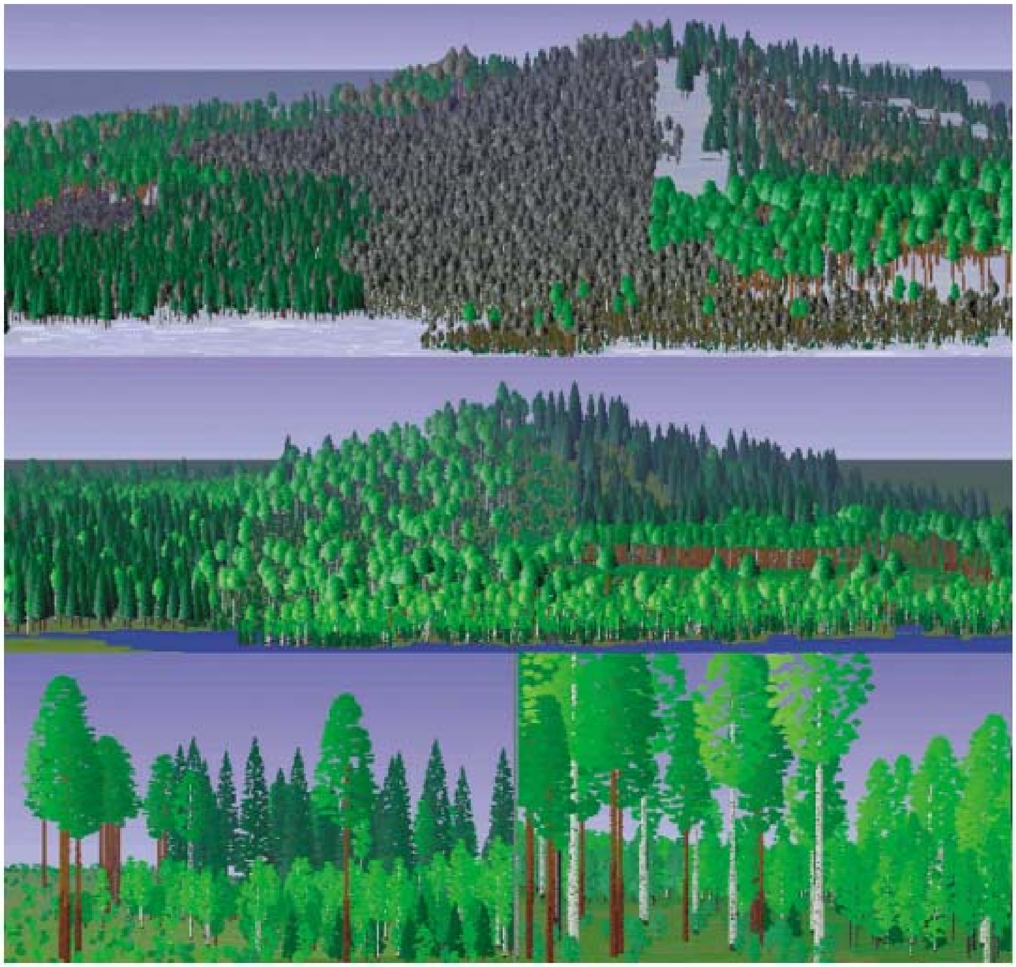

Figure 1.1: Long and near-distance views produced using MONSU (Karjalaimen and Tyrväimen, 2002).

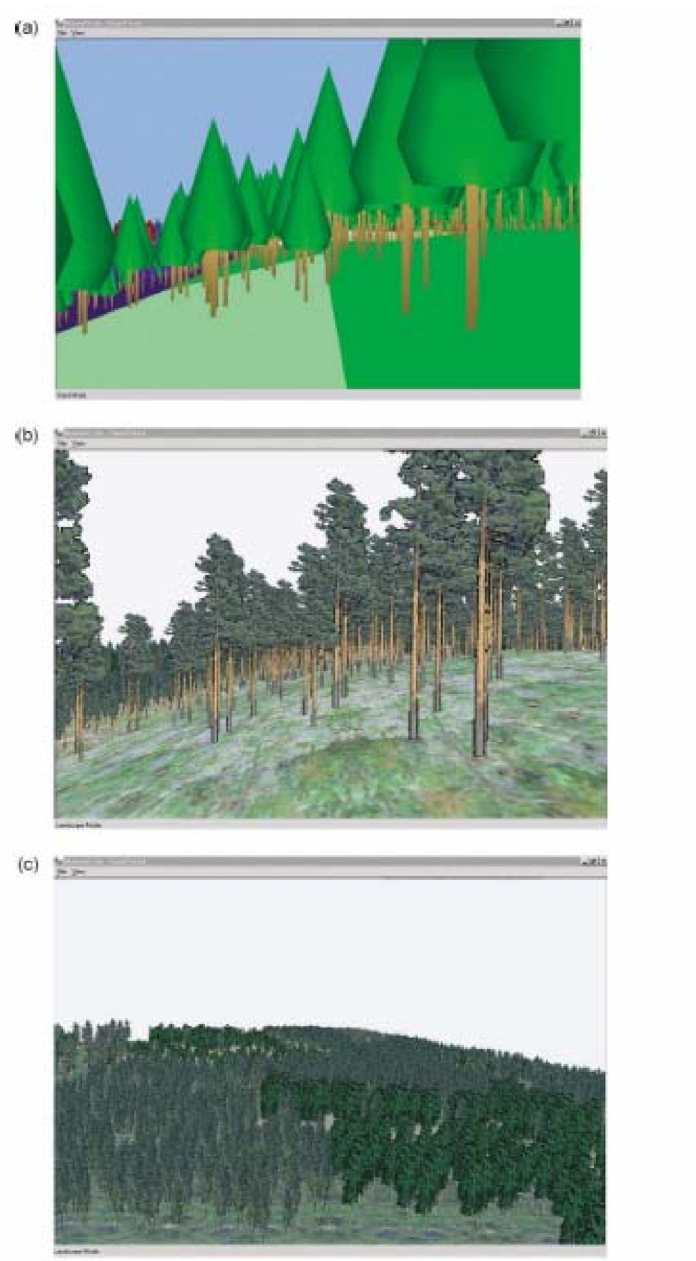

Figure 1.2: (a) Near-distance view in manager mode of Smart Forest (b) long-distance view (c) and landscape mode view produced using Smart Forest (Karjalaimen and Tyrväimen, 2002).

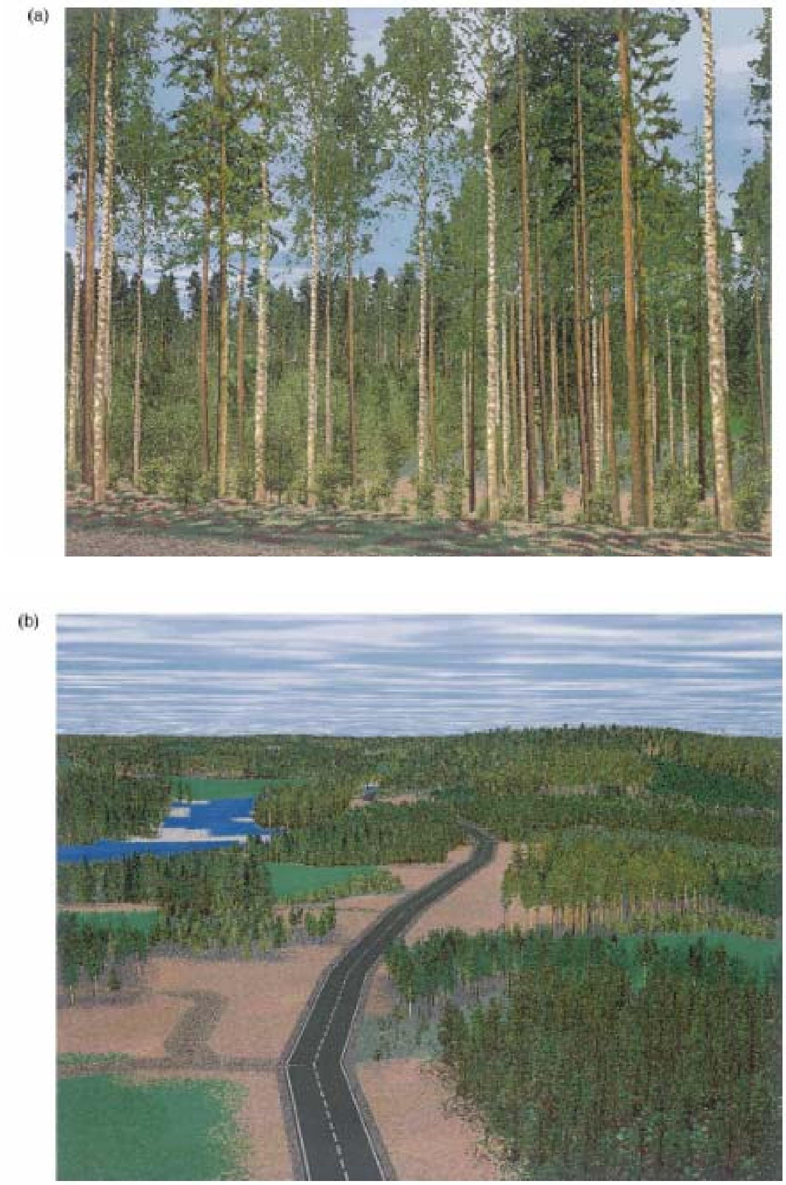

Figure 1.3: (a) Near-distance and (b) long-distance views produced using FORSI (Karjalaimen and Tyrväimen, 2002).

Because these objects are digitized from photographs, high quality images can produced that are only limited to the color depth and resolution of the original photograph. Likewise new objects can easily be added to the standard library of tree and forest elements by simply digitizing them from photograph. FORSI also has the ability to illustrate seasonal and atmospheric effects. This allows for more realistic scenes due to differing light and sky conditions. Movement simulation in FORSI is very similar to that in MONSU. Points are manually selected and scenes are drawn along that path in order to simulate movement throughout the forest.

Of these three software packages, Smart Forest and FORSI were commercial packages while MONSU was free for use (Karjalaimen and Tyrväimen, 2002). Currently only Smart Forest and MONSU have websites (http://www.imlab.psu.edu/smartforest/ and http://www.monsu.net/Englishmonsu.htm), however neither is available to download at this time. Due to their age, these software packages are no longer in use. Song et al. (2006) further investigated the use of applications for landscape visualization. One of the key challenges found to be facing software packages for use in visualization is real time interaction. Users should be given the option to replay alternative management activities such as harvesting and planting in respect to location and the timing of events. Through this study many other software packages were found to be improving on these features. Commercial software packages such as Ecomodeler/Ecoviewer (Viewscape 3D Graphics Ltd) can display visualizations with point of view and flyover capabilities in real time. Users can also include management activities and perform free navigation on a visualized landscape. Other freeware application such as Persistence of Vision Raytracer (POV-

Ray, Povray.org) was found to be capable of producing detailed, photorealistic models. Development of software with real time user interaction and photorealistic modeling helps to provide better tools for the use of visualization in landscape management.

Study Goals

The purpose of this study is to develop an extension of the visualization research done by Wang et al. (2006). Wang's research involved visualizing the landscape of the Chequamegon National Forest in northern Wisconsin using publicly available data sources such as forest inventory analysis (FIA, USDA Forest Service) and GIS data. The visualization was done using Visual Nature Studio (VNS, 3D Nature Inc.), a relatively newer visualization software package. Mathematical models were then applied to the forest data to determine changes with future succession and growth. The resulting data were applied to initial forest visualization to show changes in forest stand structure and composition that may occur due to harvesting or some other disturbance event. Resulting visualizations that came from these data were time lapsed images showing the changes of the forest over extended periods of time. Using similar methods, this study aims to develop visualizations for a wildfire event in the pine barrens of New Jersey. An initial forest environment will be constructed using public topographic, vegetation, and GIS data for the study area. Data output from the FARSITE (Miles et al, 2001; SEP, 2005) model will then be applied to the visualization in order to show the spread and effects of the fire. FARSITE is a fire behavior and growth simulator program used in the prediction of fires based on initial fuel, weather, and topographic conditions. Widely accepted, it used by a fire behavior analysts from a wide variety of agencies, including the USDA Forest Service, USDA National Park Service, and the USDI Bureau of Land Management. The program accepts vegetation, fuel load, weather, and topological data in the form text files and raster images. Output from the program consists of ArcGIS raster images with data pertaining to fire line intensity, flame length, and other fire characteristics. Using FARSITE, managers can predict the occurrence of both surface and canopy fires along with behavior based on factors such a firebreaks and weather suppression.

There are three main goals of this study, the first of which is to determine if wildfire visualization can be performed using VNS. There have been past attempts to visualize wildfires, such as the study done by the Los Alamos National Laboratory in the early 1990s (McCormick and Anrens, 1994). However, past visualization studies such as these have required both specialized equipment and programming knowledge. Likewise, the resulting output was rather crude and not very realistic. With the availability of more user friendly visualization software packages and more powerful computer hardware, the potential for easier to perform and more realistic visualization is much greater. However, no recent studies have been done exploring the possibilities of visualizing wildfires with this new technology. This study aims to determine if such wildfire visualizations can be performed. It will also determine if some of the advanced features of VNS such as atmospheric effects, light effects, and ability to include user made models can yield a more realistic visualization.

The second goal of this study is to determine the compatibility of different data formats among VNS and other GIS related software. With the rise of GIS, certain data formats have become associated with particular types of data, such as a shape file for forest stand delineations. While some software was written with these data formats in mind for use, other software may not readily accept some formats. If not readily accepted, some data may have to be converted or reformatted into a useable form for some software packages. If this conversion process is long and cumbersome it might not be ideal to use the software. Thus, examining the data format compatibility for a software package may play an important role in determining how potentially useful it may be.

The third goal for this study is a comparison between the VNS software and ArcScene extension that is part of ESRI ArcGIS Desktop. A similar wildfire visualization was done for the Hobcaw Barony in Georgetown, South Carolina using ArcScene. The resulting ArcScene visualization will be compared to the one from VNS to determine differences between the two software packages. As done in Karjalaimen and Tyrväimen’s (2002) software comparisons, several main features such as image realism, rendering speed, and movement simulation will be compared. If possible, key advantages and disadvantages for each package will be determined. Based on these factors it may be possible to determine situations in which one software package may be more suited for particular use.

CHAPTER TWO

VISUALIZATION USING VISUAL NATURE STUDIO

New Jersey Pine Barrens

The New Jersey pine barrens is a unique natural area covering nearly a million acres of the eastern Coastal Plain of New Jersey (Moore, 1939). The area consists of low relief and has sandy soils except for areas along steams and poorly drained depressions. Climate for the region is characterized by annual precipitation of between 116.8 and 121.9 centimeters (46 to 48 inches), of which 61 centimeters (24 inches) falls in a period from April through September. The number of frost free days is approximately 180 days in length, lasting from around April 25 to October 20 (USDA Yearbook, 1941). The term “barrens” was given to the area by the original European settlers due to the sandy soil and droughty conditions which prevented crops from growing (Georgian Court University, 2006). Due to geologic and climatic effects, partly related to glaciations, many plant species are at a northern or southern range limit within the pine barrens. As a result of these conditions, most of the pinelands are protected by state and federal agencies. The New Jersey Pinelands Commission is the organization that oversees the management of the protected outer regions and the inner Preservation Area of the barrens. The area was designated as the Pinelands National Reserve in 1978 and as a United Nations International Biosphere Reserve in 1983. Major conifer species in the area include pitch pine (*Pinus rigida),* Virginia pine (*Pinus virginiana),* and shortleaf pine (*Pinus echinata).*

Some of the common oak species in the area are white oak *(Quercus alba*), scrub oak (*Quercus ilicifolia)*, black-jack oak *(Quercus marilandica*), and chestnut oak (*Quercus prinus*). The area also is home to several species of carnivorous plants such as spatulate-leaved sundew (*Drosera intermedia*), round-leaved sundew (*Drosera rotundifolia*), and pitcher plant (*Sarracenia purpurea*).

Fire has played an important role in the pine barrens since prehistoric times (New Jersey Forest Fire Service, 2006). Natural fires caused by lightening strikes have influenced pitch pine populations since the Late Pleistocene period 10,000 years ago. Pine barren species were attracted to the area due to the sandy and droughty conditions. Pitch pines were favored by frequent fires that tend to eliminate competitors by maintaining the original poor habitat conditions. The native Americans that later lived in the area used fires as a tool for clearing the land. This created large areas of open land that was present when the European settlers arrived in the late 1600s. They adopted this practice to continue clearing land for agricultural purposes. Due to the more frequent use of fire with little or no regulations, major fire outbreaks often occurred and were allowed to let burn. An account from 1755 reported a fire 30 miles long that occurred between Barnegat and Little Egg Harbor. Other early surveys of the area indicated that as many as 100,000 to 130,000 acres burned annually in the pine barrens region each year. This trend continued as long as to the late 1800s. As the population of the area increased, the need for controlling the outbreak and spread of fires also increased as well. In 1905, the Forest, Park, and Reservation Commission were established and the first forest protection laws were enacted. The following year, a law establishing the Forest Fire Service was enacted. This established the State Fire warden position and Township Fire warden system. In 1910, a lookout tower system was established, and in 1927, aircraft were first used for observation. With the changes in fire management and current fire suppression techniques, the current fire regime of the pine barrens is greatly different than it was originally, having fewer outbreaks and a lesser extent of area burned.

Pitch pine is one of the major fire species that plays a role in the fire regime of the New Jersey pine barrens. Pitch pine forests have been described as “fire dependent ecosystems” due to various fire-adapted regeneration strategies and both persisting in and fostering environments conductive to ignition, combustion, and fire spread (Gucker, 2007). Trees often have drooping, slender branches along the lower bole and persistent dead branches containing more resin than live branches. They may also retain the previous year’s growth of vegetation on the tree for up to two or three more years. These features of pitch pine can provide for a large amount of combustible material in the environment to act as a fuel source. The long growing season, high maximum temperature, strong winds, and level or rolling terrain of the New Jersey pine barrens further encourages the ignition and spread of fire. Pitch pine is resistant to fire; however, in some cases trees may be top-killed or killed. The bark of pitch pine is very heat resistant, forming a barrier that covers the inner bark. A thick covering of bark also protects basal and dormant buds that occur within the trunk and crown.

When subjected to a fire, pitch pine responds in several different ways. Trees are capable of producing sprouts from buds at the internodes of multinodal stems. The dormant buds are protected by the bark or develop into short branches of isolated fascicled needles. These dormant buds can grow very quickly and within several days needle fascicles may appear along the bole or larger branches. Sprouting may also occur from basal buds that are protected by the bark or basal crooks. However, basal bud survival is usually linked to fire severity, with high mortality occurring with more severe fires. Pitch pine may also recover from fire through seed production and establishment. In areas of frequent fires, trees may possess serotinous cones. Seeds can be held within serotinous cones for up to 10 years and be insulated from high temperatures. After exposure to temperatures high enough to melt the sealing resin, the seeds are released into the environment. Seed establishment is very favorable in these conditions due to the removal of other competing vegetation. Each of these forms of regeneration can be used by pitch pine for recovery from a fire; however, research has found that with increasing severity, the predominant method changes from bole and crown sprouting, to basal sprouting, to seedling establishment.

Visual Nature Studio Visualization Methods

The computer system for working with VNS was a custom built system with an AMD Athlon X2 4200+ dual core CPU, 2 gigabytes of RAM, and an nVidia GeForce 7600 GS graphics card. An updated version of VNS version 2.7 was used for the study. Add on tools such as Scene Express or the Forestry Edition were not installed or used.

A 2,590 hectare (10 square miles) section of the Cedar Bridge area in the pine barrens was selected as study site. This area consisted of mainly a mature pitch pine canopy with a small amount of hardwood species and high shrub loads present in the understory. Most of the area is forested; however, there are some small areas with buildings and several highways. There is also one large lake and several smaller water bodies within the area (Figure 2.1).

One of the first steps in this visualization was to recreate the forest environment in the pine barrens. Elevation and base heights for the landforms were obtained from a 10 meter digital elevation map (DEM) that was imported into VNS. A georeferenced aerial photograph was then used to digitize surface features such as roads, urban areas, and bodies of water. Surface features were digitized from the photograph using ArcMap as shape files. The shape files were imported into VNS in order to visualize the surface features. Road and water features were visualized using the included models in VNS which looked similar to the features observed in the photograph. Urban areas were similarly visualized with a model similar to asphalt, but with little or no buildings. This was done to reduce the total number of models in the visualization and to increase rendering speed.

To visualize the forest vegetation, user-made tree models were used instead of the models included with VNS. These tree models were made from photographs of local pine barren tree species taken with a Nikon D70 digital camera during a visit in the summer of 2006. The photographs were loaded into Adobe Photoshop where surrounding vegetation was removed to leave the tree of interest alone in the foreground and the background was painted black.

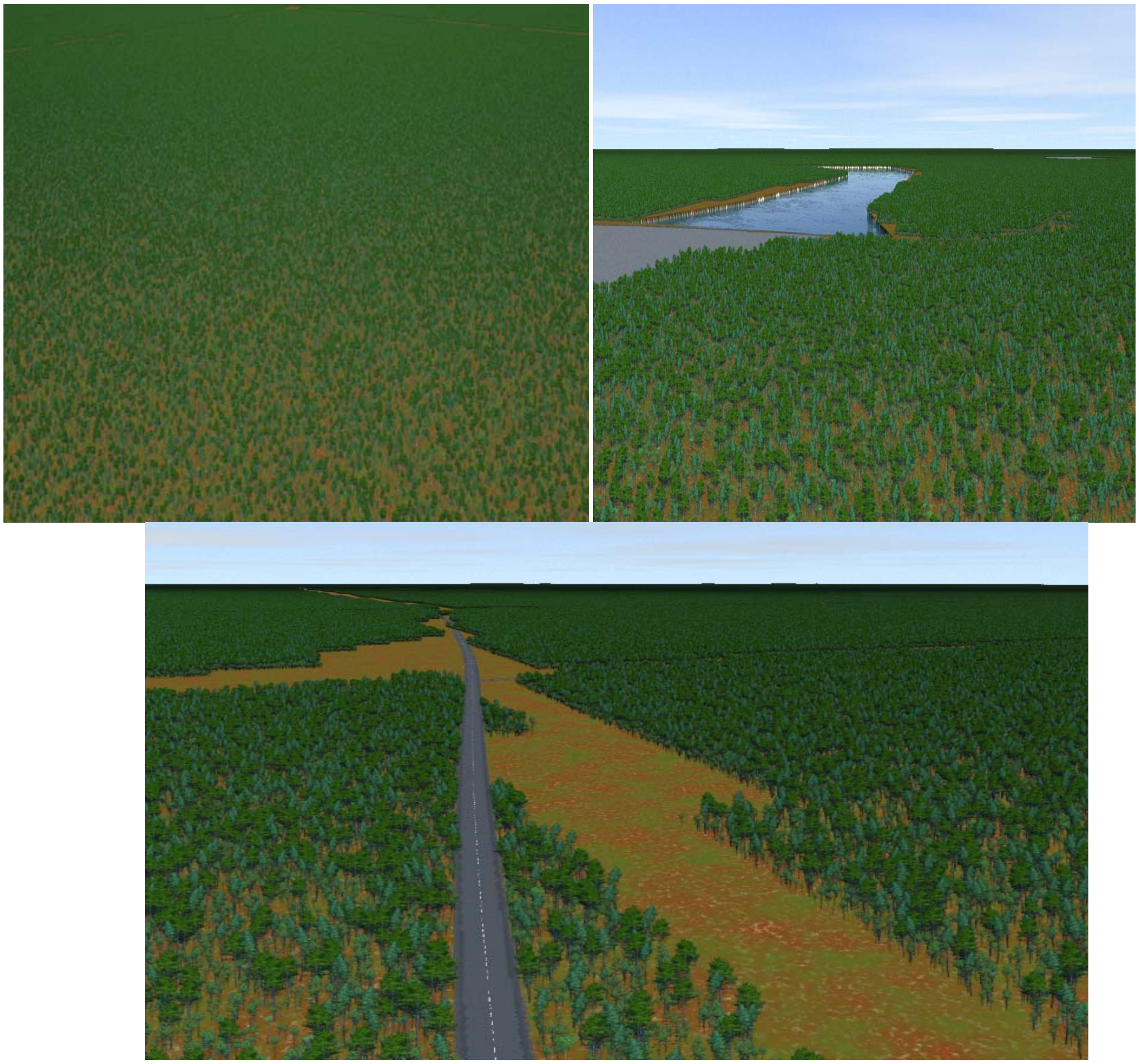

Figure 2.1: Visualization of New Jersey pine barrens before fire showing surface features such as roads and lakes.

They were saved as a JPG (JPEG, Joint Photographic Experts Group, compressed image) file and imported into the VNS graphics library to use as models.

To visualize the forest environment in a realistic manner, it was necessary to link the tree models with the actual forest structure in terms of characteristics such as tree height and density. This was done using forest inventory data and a georeferenced Canopy Bulk Density (CBD) map (Figure 2.2). The forestry inventory data from test plots included tree height, species, diameter at breast height (DBH), basal area, and density. An analysis of the data was done to determine the average and standard deviations for the tree height and DBH in each plot. Test plot density was compared to values from the CBD map based on the equation for deriving Canopy Bulk Density in mixed conifer environments developed by Cruz et al. (2003):

$$\ln(CBD) = (0.319 * \ln(\text{basal area})) + ((0.859 * \ln(\text{tree density})) – 8.445$$

When solved for density using the values from inventory data and the CBD map, the numbers obtained were very close to measured density in the test plots. Due to this correlation, the CBD map proved to be a suitable link between the visualization and physical inventory data. It was imported into ArcMap where each map symbology value was given a significantly different RGB (red, green, blue) color code and then exported as a GeoTIFF file (a Tagged Image File Format image retaining its spatial coordinates). When imported into VNS, this GeoTIFF acted as a color map to visualize varying forest ecosystems of different structure based upon the CBD value (Figure 2.3).

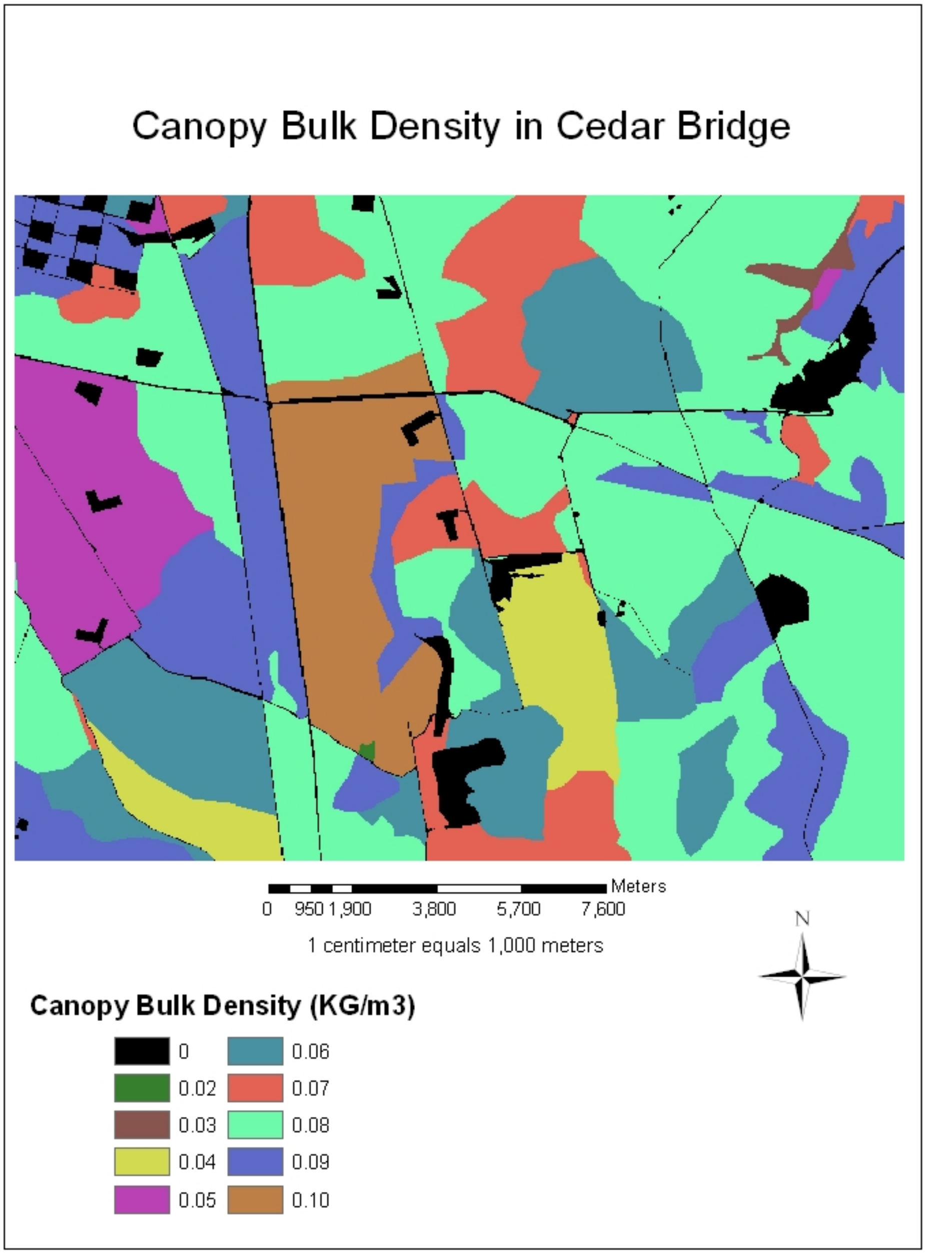

Figure 2.2: Canopy Bulk Density map used for linking vegetation data to the visualization model in VNS.

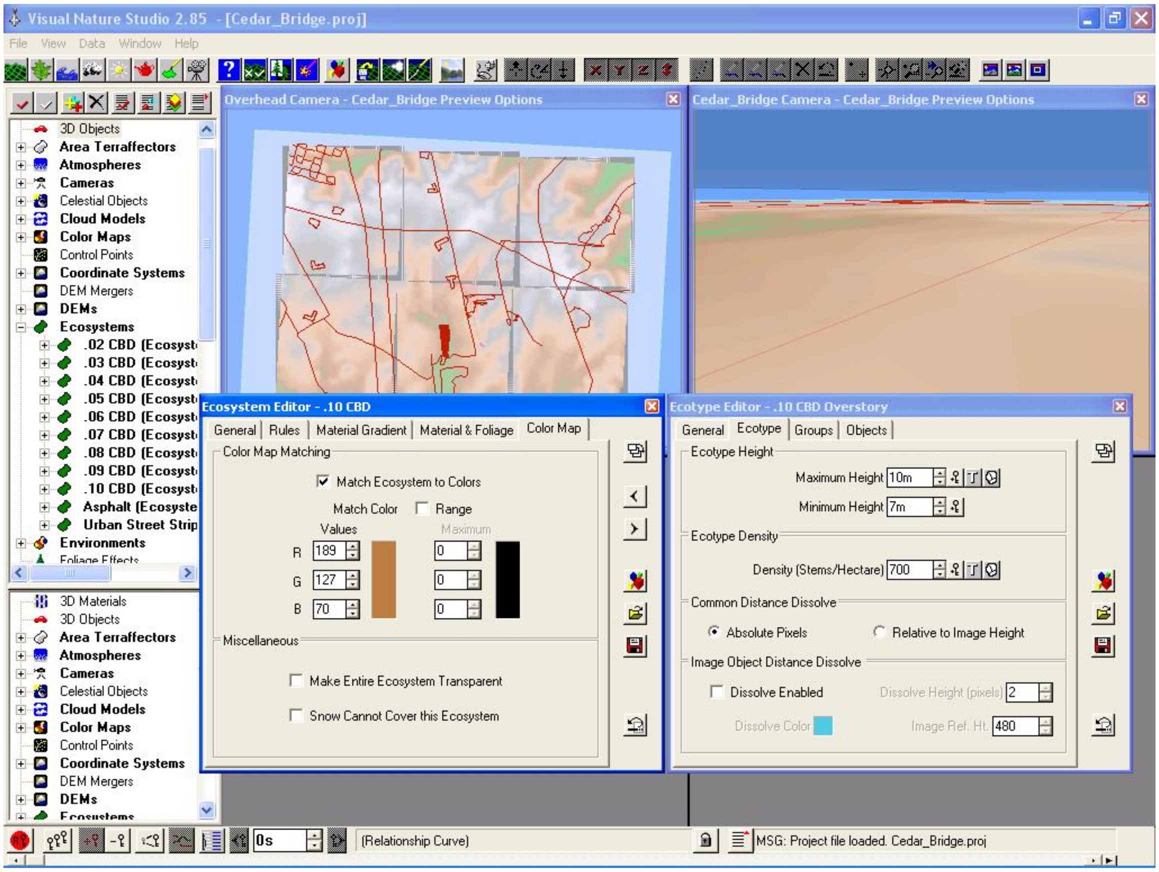

Figure 2.3: An example of matching up ecosystems to RGB values from Canopy Bulk Density values within VNS.

Varying forest "ecosystems" were constructed using the ecosystem function in VNS. An ecosystem is defined in VNS as an association of plant species all sharing common characteristics such as height, density, and relative frequency. Appropriate tree models were placed in the canopy and understory layers based on species from the inventory data. Average height was used for the main tree height while the standard deviation was used as an offset factor to vary tree height. An included ground texture representing a forest floor with leaf litter was assigned to represent the ground. Due to the uniform nature of the site most of these ecosystems were essentially the same in terms of species type, tree heights, and DBH classes. The most noticeable differences were in tree numbers and density, which was reflected in the CBD values used for color mapping.

Final preparations for the initial environment were to place some final aesthetic components into the visualization. These were features such as sky and cloud models, atmospheric lighting, and shadows. Most of models were added from VNS' built in library of objects with a small amount of editing. Such components were not critical for visualizing forest structure; however, such details add realism to the scene by representing aspects as they would appear in nature.

Wildfire data was obtained from FARSITE simulations performed by Matthew Duveneck of Southern Maine Community College. The simulation was performed based on the conditions in the area for April 4, 2005 to recreate a fire that had occurred within the area previously. Temperature ranged from 4.8 to 18.9 degrees Celsius (40 to 66 degrees Fahrenheit) with a humidity range of 16 to 61%. Wind speed ranged from 14.5 to 20.3 kilometers per hour (9 to 13 miles per hour) for the day. The wildfire was simulated over a series of 30 minute increments from 12:30 to 6:30 PM EST. Results from the simulation included a shape file outlining the spread of the wildfire over each 30 minute increment and several raster files with data pertaining to flame length, fireline intensity, and crown activity (Figure 2.4).

The custom tree models for tree visualization were recolored using Photoshop to represent burned trees. Models representing slightly burned trees remained mostly green, but had a small amount of brownish hue in the lower foliage and trunk. Additional yellow and red hues were added to the foliage to represent trees receiving more medium type damage. For more severe damage a larger amount of red hue was added to foliage along with darker brown color or black marks to the trunk. Completely burned tree models had all foliage removed with very dark brown or black trunks and branches. A collection of flame models were also used to show fire occurrence (Figures 2.5 and 2.6). A few models were drawn with Photoshop for the purpose of representing ground and understory fires. Another group of flame models came from a collection of Photoshop brushes created by Shimerlda (2007). These flame models were combined with the burned tree models to represent fire burning through the various layers of the canopy. Each tree model of different burn severity was merged with a corresponding flame model to represent fires occurring in the low, midstory, and top canopies of the trees. To represent fire moving through canopies of a group of trees, the larger flame models were merged with groups of three or four of the tree models.

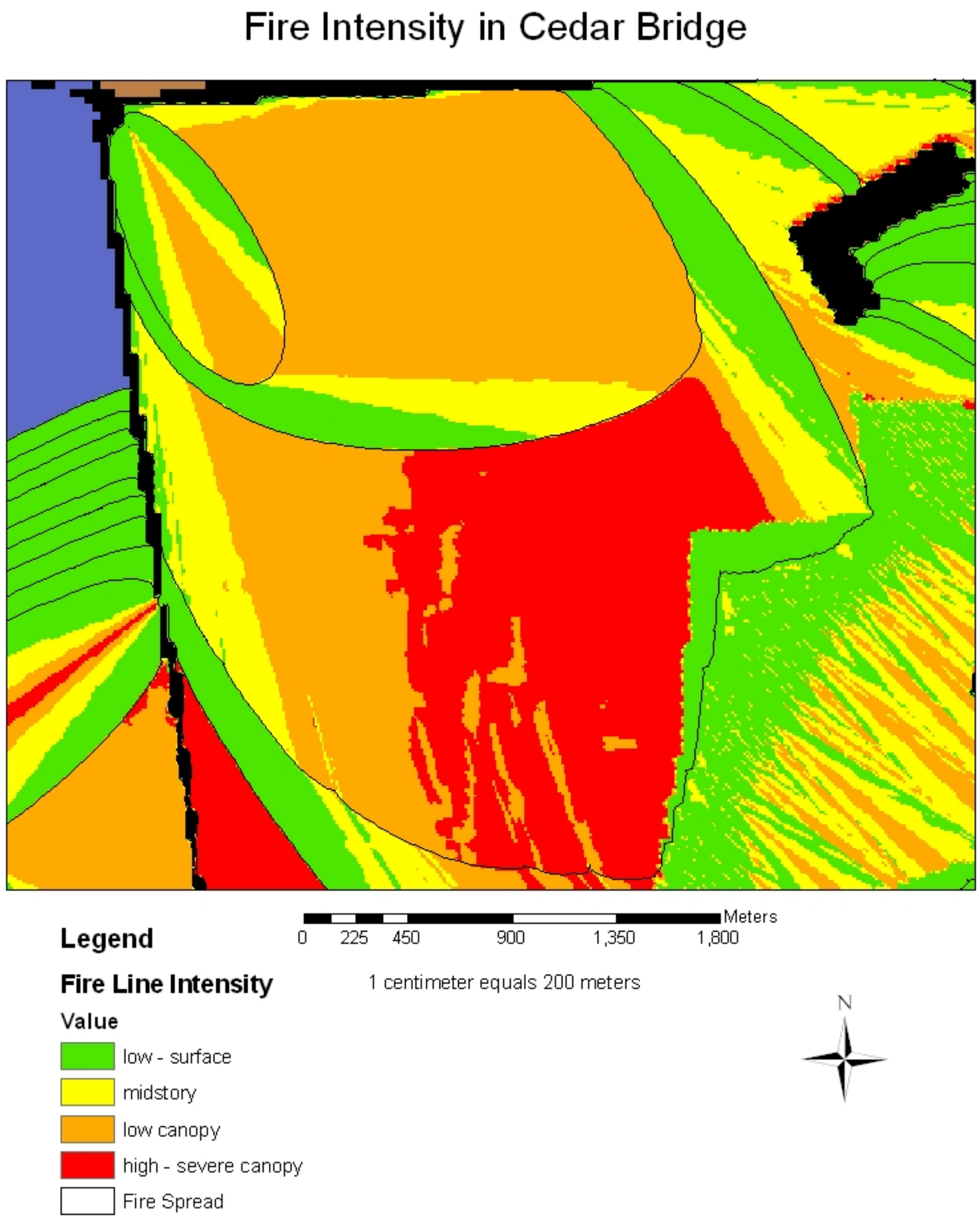

Figure 2.4: An example of FARSITE output showing fire line intensity within the pine barrens study area.

Figure 2.5: Example of custom models used to illustrate fire damage. Individual tree models were edited to show varying degrees of damage based on severity. Different flame models were used to show movement of fire through the canopy.

Figure 2.6: Additional custom models for illustrating fire damage. Several tree models were used together with a larger flame in order to show movement of fire across the canopy.

Visualization of the wildfire was performed in a similar manner to different ecosystem placement using the CBD map. Examining the fireline intensity and flame length output in ArcMap show a strong relation; areas of intense fire typically had flames of greater length. Due to this, the flame length output was chosen to serve as a color map to guide proper fire visualization. Four different fire severity environments were constructed based on flame length; ground and understory fire for lengths of 0 to 3 meters (0 to 9.84 feet), midstory from 3.01 to 6 meters (9.875 to 19.69 feet), overstory from 6.01 to 10 meters (19.72 to 32.81 feet), and fire extending over the top canopy from 10.01 to 16 meters (32.84 to 52.93 feet). Three different burned environments were also constructed to show the effects of a fire passing through the forest; one for areas in which the flame front had just moved through it, another for areas with low intensity and flame length, and one for areas with high intensity fires. These environments were constructed similarly to the regular forest environments in which the appropriate burned tree models were selected for each one. Ground textures were made using Visual Nature Studio’s texture editor. The basic ground texture was edited to show increasing amounts of damage with increasing fire intensity. These different environments were then assigned to each of the different forest ecosystems as a material. Materials in VNS act much like an ecosystem with each possessing tree heights, density, ground models, etc. However, materials inherit all their characteristics from their parent ecosystems. As with the CBD map, the flame length raster and fire shape files were imported into ArcMap for editing to make a color map. Within each 30 minute increment of the fire as defined by the shape file, the map symbology of the flame length raster was changed to a varying grayscale

RGB value for each type of fire ecosystem. As the fire progressed, it was necessary to change the type of ecosystem present in already burned areas to reflect the behavior and effects of the fire. Based on consultation with Matthew Duveneck (personal communication, 2007), it was estimated that a lowering of fire intensity would usually occur sometime during 30 minutes of the flame front moving with a complete burn out occurring after about an hour. Each of these edited images were saved as a GeoTiff and imported into VNS as a color map. The individual images were placed as a second color map overlying the original CBD color map. The use of both color maps was needed so that the proper forest ecosystem type was selected first and then the proper fire/burn materials within that ecosystem were visualized.

Animations were produced using the included animating editor. VNS' animation editor functions as a sequence moving through key frame images. Each key frame image is rendered in sequence as a still frame with VNS adding a transition between each frame. When combined, it produces a seamless animation through the entire sequence. By default, VNS saves animations in Window's .WMV format, but other formats such as QuickTime or .AVI can be made if the proper codec (a set of instructions for playing a specific computer media format) is present.

CHAPTER THREE

VISUALIZATION USING ARCSCENE

Hobcaw Barony

Located on the southern tip of the Waccamaw Peninsula along the South Carolina Coast, Hobcaw consists of 7,000 hectares of land set aside as a wildlife refuge and forest/wetland research facility. Hobcaw has a very gentle topography and the average elevation of the area ranges from 3.048 to 7.62 meters (10 to 25 feet) above sea level. The climate is consistent of that of a temperate climate. Average yearly land temperature is 18.2 degrees Celsius (64.8 degrees Fahrenheit) and the average ocean temperature is 19.4 degrees Celsius (67 degrees Fahrenheit) (SC Climatology Office, 2007). Average yearly rainfall is 131.064 centimeters (51.6 inches). Hurricanes can also occur in the area from June 1st to November 30th.

On Hobcaw, there are about 3,000 hectares of forests, 3,000 hectares of saltmarsh, and 1,000 hectares of freshwater or brackish marshes and abandoned rice fields. Barry and Batson (1969) described the species composition of the forested areas. Sixty-one percent of the forest is pine stands, composed of 22% loblolly pine (*Pinus taeda*), 21% longleaf pine (*P. palustris*), and 18% mixed pine. About 20% of the forest cover consists of pine-hardwood stands while upland hardwoods account for 11%. Bald cypress-tupelo (*Taxodium-Nyssa)* stands account for about 5% of the area, and open fields, including young regeneration areas, account for almost 3%.

As described by Williams and Lipscomb (1983), forest structure prior to Hurricane Hugo in 1989 was the result of four distinct management regimes. Pine stands, many of which are over 100 years old, originated during the bankruptcy of the rice planters which owned the property in the 19th century. Many of the upland fields were abandoned in the 1870s, while other stands show a significant amount of regeneration from 1870 to 1900. From 1906 to 1956, the forest was owned by Bernard Baruch. He managed the forest primarily for quail and duck hunting. This management pattern relied mainly on periodic burning that is still commonly used by other plantations in the Low country. From 1936 to 1956, the land was gradually purchased from Bernard by his daughter Belle. After the last purchase, a program of natural regeneration was begun in which 3,700 acres of pine lands received shelterwood and seed tree cuts. By 1975, only 1,400 acres of the cut-over land had successfully regenerated, mainly on moderately well drained soils. After Belle's death in 1964, the Belle W. Baruch Foundation was established to manage the property for research purposes. From 1969 to 1997, the Foundation contracted with Clemson University to collect forest inventory data and advice on management practices. A major effort during this period was to regenerate pine in areas that had failed to regenerate previously. Understory and midstory control in areas of poor regeneration was also another major management focus.

Due to the protected nature of the site, large-scale forest management practices are generally not used. Annual prescribed fires are often employed to control the fuel loads in areas of high fire hazard. Periodic burning is also used to maintain habitat for red cockaded woodpecker stands. Since 1975 long rotation forest management has been practiced, which includes periodic tree harvesting and regeneration cuts. Salvage logging was employed after catastrophic disturbance events such as Hurricane Hugo in 1989, which resulted in large numbers of salt-damaged and windblown trees.

ArcScene Visualization Methods

The visualization produced using ArcScene was done on a Gateway laptop computer system with an AMD Athlon 3400+ 64 bit processor, 512 megabytes of RAM, and an ATI 200M Radeon Express video card. The ArcScene extension included as part of the 9.2 version of ArcGIS Desktop was used.

Preparation for visualization began with the analysis of 1986 stand data for Hobcaw. The stand data were collected using a series of test points within each stand where features such as diameter at breast height (DBH), species type, and height were collected. The Hobcaw 4 stand compartment was determined to be the best area to be used for this study due to the frequency of prescribed burning and the large amount of data available for the area. To analyze the data, trees from each test point within the stand were separated into species groups. Each tree in a species group was then placed into one of three DBH classes which consisted of groups ranging from 4 to 9 inches, 10 to 14 inches, and those greater than 14 inches. The total number of trees and relative number of trees occurring in each DBH class for the test point was then calculated. The number of trees per hectare, average DBH, and average tree height was then calculated for each DBH class. These sets of calculations were carried out for each of the test points within the stand and were repeated for other stands within the compartment. The resulting numbers were then combined and averaged to produce representative values for each of the tree species occurring within in each of the stands making up the Hobcaw 4 compartment.

Tree crown positions were then determined from a series of georeferenced aerial photographs of the stand compartment. The photographs were loaded into ArcMap 9.2 and crown positions were selected manually by identifying trees as points. Two separate shape files were created for the crown positions, one for conifers and another for hardwoods (Figures 3.1 and 3.2). After the points were selected, tree species were assigned to them. Using the random point selection feature of Hawth's Tools for ArcMap, species types were assigned using the percentages of different species within the stand calculated from the inventory data. In most cases, this proved adequate for defining the species composing a stand. However, there were a few instances where species type was assigned manually when it could very easily be determined from the photographs. DBH classes were also assigned in a similar manner to species type. Although DBH classes can be correlated to canopy areas, the large amount of tree canopies within the compartment made digitizing individual tree canopies rather difficult. Likewise, in areas of dense trees, it was sometimes difficult to distinguish between individual trees. To simplify things, DBH class was randomly assigned to points based on the species percentage and relative number of trees occurring in each class within the stand. From the DBH class, an average height determined by the calculated stand data was assigned to the point.

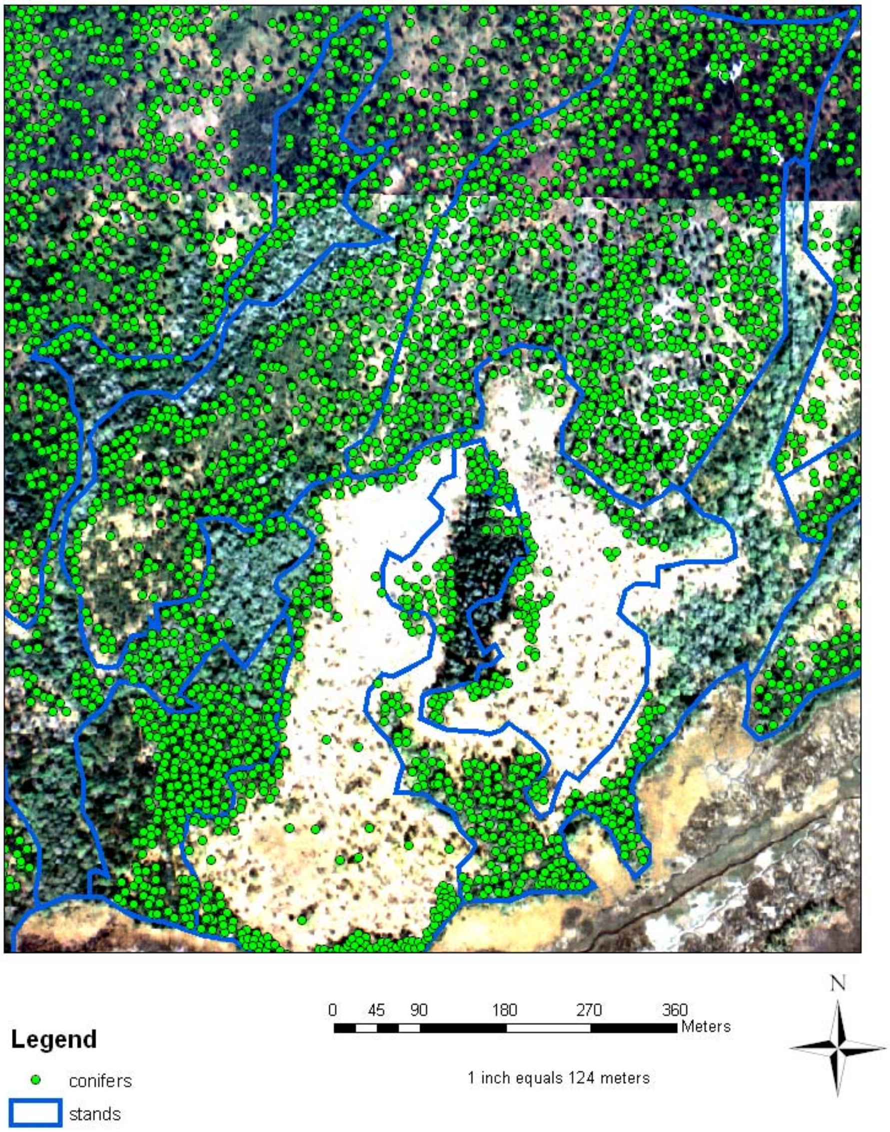

Figure 3.1: Tree canopy position of conifers within Hobcaw 4 compartment.

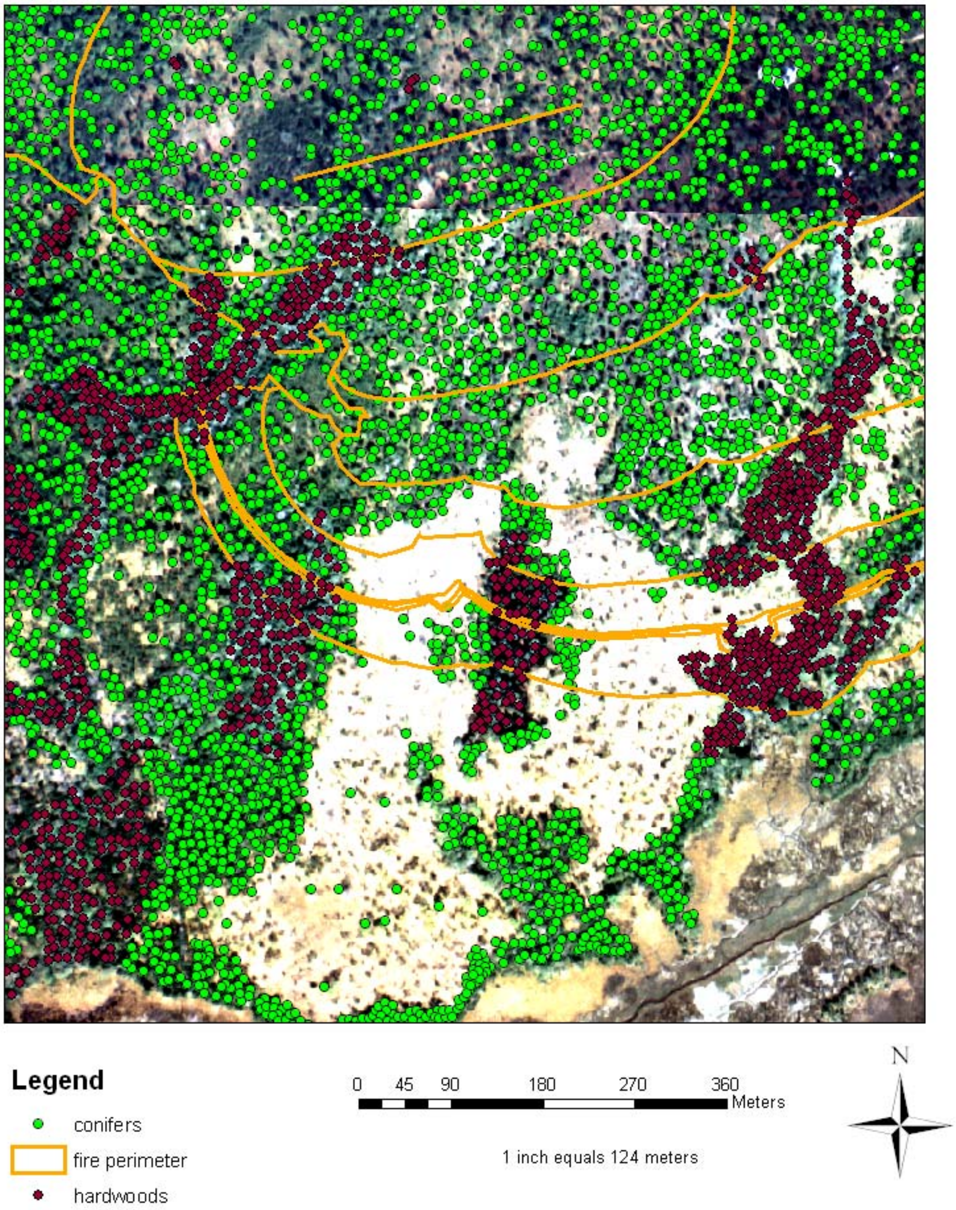

Figure 3.2: Tree canopy positions of hardwoods and fire spread in Hobcaw 4 compartment.

This average height had a value falling within the upper and lower range based on the standard deviation of tree heights from the stand inventory data.

Stand visualization was performed in ArcScene 9.2. Ground surface and initial base heights were determined from a DEM of the stand area. Surface features such as roads were visualized using shape files of those features. Appropriate models for the surface features were selected from ArcScene's included model database and then visualized on the surface. Visualization of trees was done using the crown position shape files determined from the aerial photographs. Like the surface features, tree models were also selected from the model database and projected from the surface. Tree height was displayed by arranging each tree species into different height groups. For each group, the size of the representative tree model was adjusted to reflect the differences in height.

Fire simulation was performed using the FARSITE software package. Initial conditions were set to simulate a typical prescribed burn; temperatures of about 12 degrees Celsius (55 degrees Fahrenheit), relative humidity of about 40%, northwest winds ranging from 16.1 to 24.1 kilometers per hour (10 to15 miles per hour), and duration of 6 hours. Slope and elevation information was obtained from performing the subsequent functions in ArcMap using the DEM of the compartment. A rough estimation of vegetation and fuel loading was done using the aerial photographs in conjunction with the stand inventory data. Mostly understory vegetation was considered as the possible fuel types since the simulation was that of a short duration prescribed fire. Output of FARSITE consists of a shape file describing fire spread and burning conditions. The resulting shape file was imported into ArcMap along with the tree position shape files.

Tree points were selected as either being inside or outside the fire spread area. For those falling inside the area of fire, the trees were analyzed to determine if any damaged occurred. The tree position in relation to fire spread and damage occurring was added to the position shape files as new column data. This process was repeated every two hours for the duration of the burn. The modified shape files were then imported back into ArcScene to visualize the simulation output (Figure 3.2). Tree species models were recolored for those points that fell within areas of fire spread. For each increment of the fire duration, the compartment data was visualized to show the spread of fire and those trees that fell within the area of fire spread that were affected or damaged by it.

To produce an animation of the visualization, a still frame screen capture was taken for each of the two hour increments of the fire. These images were imported into a program capable of producing animations from still images. The images were essentially spliced together to produce an animated GIF file of the fire. ArcScene also has a built in flying feature that can be recorded as an animation. However, this feature was not used in this study because it only produces a flythrough in a static scene.

CHAPTER FOUR

RESULTS AND DISCUSSION

As demonstrated by this study, Visual Nature Studio and ArcScene are capable of producing visualizations for wildfires, with both still and animated images being produced (Figures 4.1, 4.2, 4.3, and 4.4). Furthermore, it shows that such visualizations are capable of being produced on a computer system running standard equipment. Despite being custom built, the system used for this study possessed hardware easily purchased at most computer specialty stores. Likewise, the software applications used were standard for their given use; Photoshop for graphics and Arc Desktop for GIS analysis. Some specialized skills were needed for the graphics work to produce the custom models or for using VNS, however, no real programming experience was needed in order to construct the visualization. Unlike some past studies which needed custom programming to extend the capabilities of the visualization program, all the features needed for this study were included as part of VNS.

The still frame images and animations produced effectively showed the spread of the wildfire and its effects on the environment (Figures 4.2, 4.3, and 4.4). By combining the burned tree models with different flame models, the fire's movement through the canopy could be shown. The different models used illustrated the movement from the forest floor to the upper canopy of the forest and beyond. The different burn environments also showed the effects of the fire on the forest.

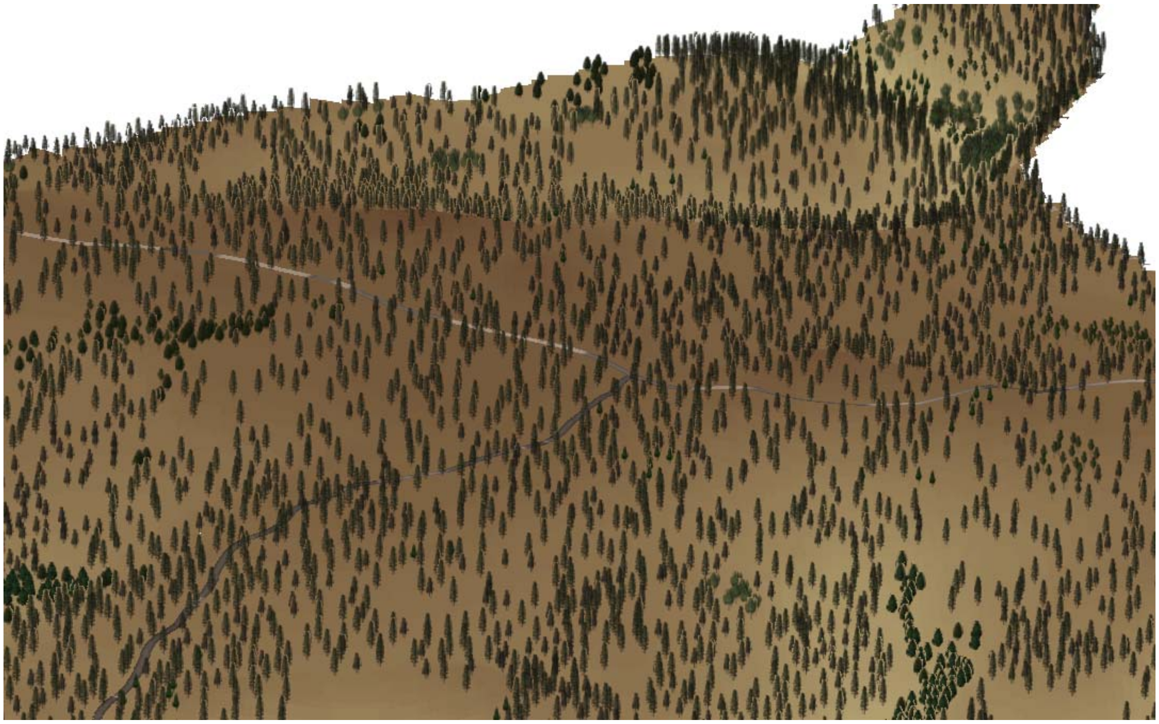

Figure 4.1: Example of ArcScene visualization.

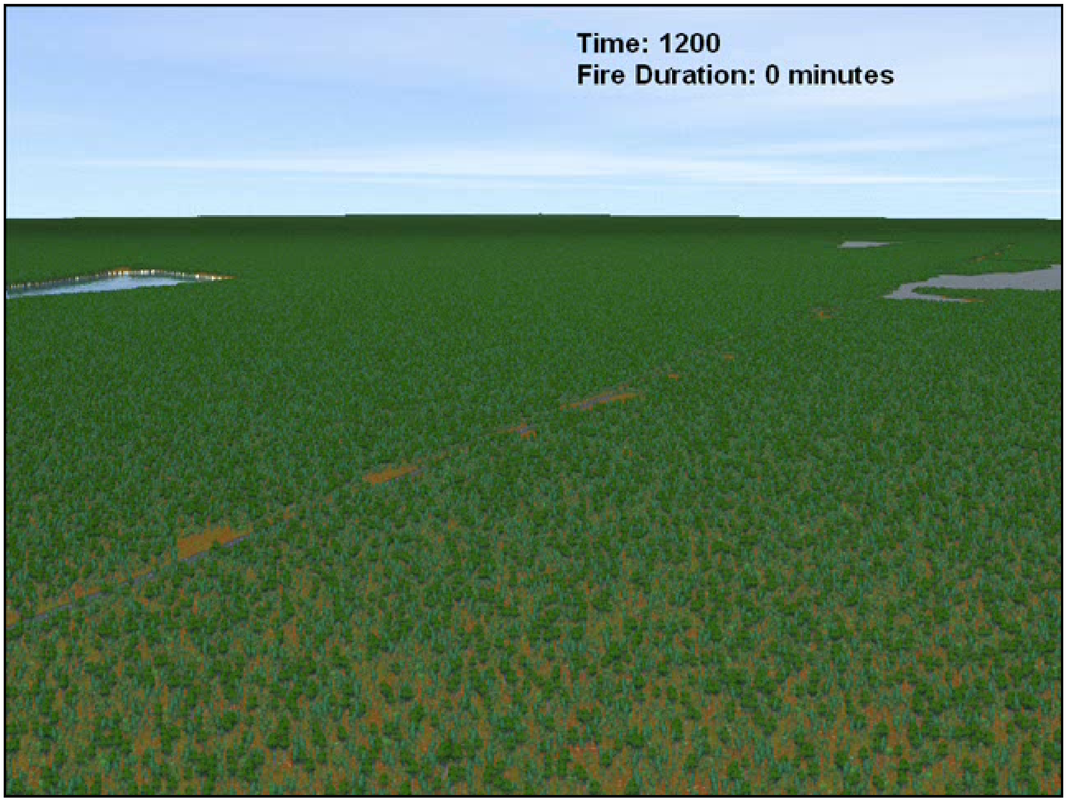

Figure 4.2: Animated VNS visualization of pine barrens fire. This animation shows the progression of the fire over the entire six and a half hours in 30 minute increments as determined by the FARSITE data.

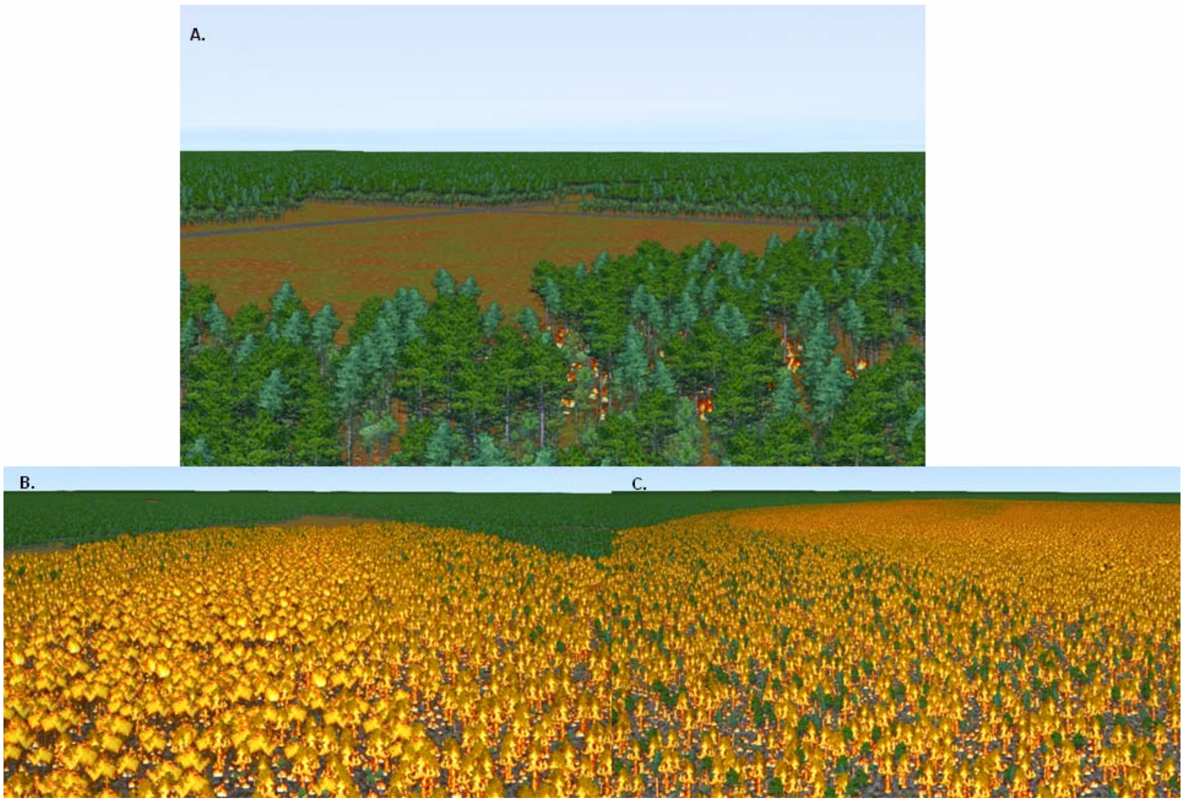

Figure 4.3: Example of VNS visualization with fire in different canopies of the forest (a). surface fire (b). upper canopy (c). mid canopy. The position of the fire within the forest canopy relates back to the flame length output of FARSITE.

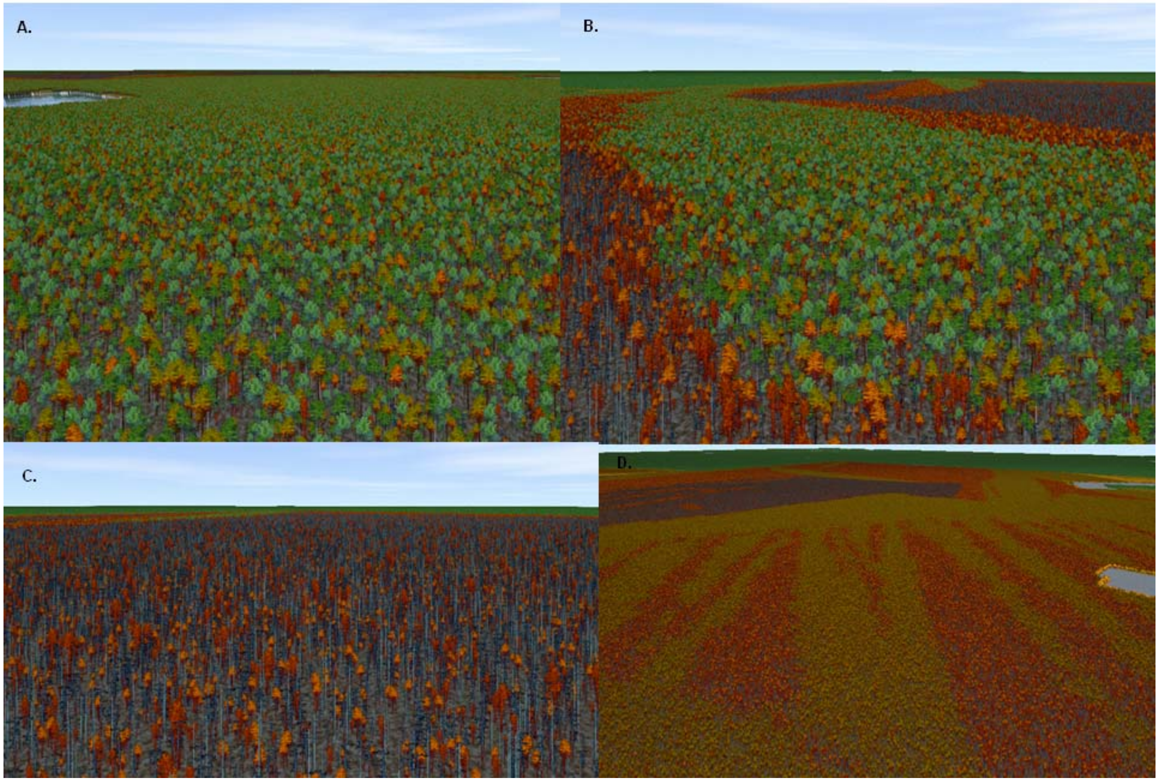

Figure 4.4: Example of VNS visualization illustrating different levels of burn severity (a). surface fire (b). mid canopy (c). upper canopy (d). landscape level. The varying levels of severity can be linked back from the fire line intensity output of FARSITE.

Tree models in each of the environments reflected fire severity and intensity, with high areas having almost total burned trees and low areas having trees with little or no damage. The edited ground textures served to show fire effects on ground and understory layers. With increasing severity, the textures grow darker with more and more understory material being burned out. Through the use of VNS' more advanced features, the scene realism is enhanced with effects such as clouds, lights and shadows, and reflections on water. As suggested by past visualization research, such realism allows observers to more readily identify with a scene. With such easy identification, observers are able to perceive it more easily and draw more meaningful conclusions.

There were several aspects that were detrimental to the realism of the visualized wildfire. One of these aspects is the occurrence of a solid wall of flame for each fire type. Ordinarily there should be an active fire front with varying levels of fire intensity behind it based on fuel types and amounts. Something similar was planned for the visualization but the mechanics of the shape file prevented it from being implemented. The area for each 30 minute increment within in the shape file extended outward from the initial point of ignition. Using the outline of that area for a flame front would have yielded an unrealistic image resulting in a flame front occurring all the way back to the original ignition point which may have already burned out. Likewise, the raster images for flame length had to be reclassified into smaller groups more easily managed for visualization, so not a lot a variety could be done. Therefore, areas of fire are best thought of as representations of the fire severity occurring over the area at the time, not as the fire actually occurring. Another problem for realism was the large extent of the study area. The large size made showing events over the whole area difficult to illustrate. Just to show the first three hours of the fire required the camera to be at height of nearly 150 meters. Such a height made showing areas further away difficult because many of the details were lost or they were almost indistinguishable. Attempting to show the entire wildfire in one scene would be extremely difficult and result in nearly all the details of faraway viewpoints being lost.

Data Compatibility

Various data formats showed great compatibility with VNS. Shape files, raster images, and DEMs were easily imported and used with no conversion necessary. Once imported, they could easily be used to visualize ground heights or other features based on the table attributes. Image files, such as JPEGs and bitmaps, could be imported easily to be used as custom models, but sometimes required some modification using Photoshop to paint the background black for a transparency mask. Georeferenced maps could be imported as imported color maps. However, some work was needed changing the RGB values in the map symbology due to VNS having difficulty distinguishing similar colors.

Data formats also showed a strong degree of compatibility between VNS and ArcScene. Features in shape files could be used in a similar manner in both programs. In fact the shape files from the ArcScene visualization could be easily imported into VNS and used with almost no modifications. DEMs and raster files could also be used by both applications as is with no modifications. Custom models for VNS are not compatible with ArcScene due to a difference in file formats for models being used. There is also no function for using georeferenced images as color maps in ArcScene. Such images can be used as an overlying graphic for a scene, but there is no function for ecosystem matching such as in VNS.

Visual Nature Studio: Strengths and Weaknesses

Visual Nature Studio has several advantages for producing realistic visualizations of a scene. One of these advantages is the ability to import user made images as custom models. This feature is extremely useful for constructing more realistic tree models. Many of the other visualization applications such as VistaPro, Bryce 3D, and even ArcScene have tree models that are either very simplistic or composed of geometric shapes. While functional, these models may not look quite realistic or be recognizable by observers. By using photographs of the actual tree as models they look much more real and recognizable. In addition, there are options to vary the height and direction for the custom tree models. Custom models help recreate the variation among trees that is found in a natural forest. The custom model feature also allows the user to utilize models that are not part normally part of VNS' graphics library, such as the flame models used in this study. It extends the function of VNS so that aspects not originally part of the application can be modeled and visualized.

Another advantage is the ability of VNS to use georeferenced images as color maps. Using each unique color as a guide, ecosystem matching can be done on the visualized landscape. Through this matching, forest ecosystems can be visualized more accurately as to how they appear in nature. They can be shown in the correct locations within the environment. Furthermore, two or more different color maps can be used for the same set of ecosystems. This allows for uses such as before and after visualizations of a disturbance event or showing how a forest landscape changes over time. Another feature of the ecosystem mapping is the option to blend the edges of two different groups together. Raster images usually used for color maps have divisions with blocky shapes due to the information stored in each pixel. The blending of the edges allows for ecosystems to appear more like they would in nature, merging in with the one next to it instead of instantly stopping after an imaginary line.

While the included tree models in VNS are rather poor, many of the other included models are of high quality and more realistic. Most of these models are part of the built in tools used to simulate the general environment. These models include different types of clouds, water types, roads, ground textures, and sky models. The collection of high quality environmental models plays an important role for enhancing the realism of the scenes. Such high quality, realistic scenes have been found to be more effective for visualizations due to the observer's ability to identify with them more effectively. This collection of models is an advantage for the user as well because it reduces the amount of custom models needed if necessary. The user is able to quickly construct the base of the environments using the included models and then spend more time constructing custom models more crucial to the visualization. If every single model needed to be constructed by the user, making visualizations would be a long and cumbersome process.

While using VNS has several advantages, there are several characteristics of the application that can be seen as a disadvantage. One of these disadvantages is the somewhat high hardware requirements needed for running VNS. The New Jersey pine barrens visualization was first attempted on the same laptop system that the ArcScene one was performed on. However, it was quickly determined that this system was not suitable due to a lack of response while using VNS and the increasing size of project files. While several of the hardware requirements were near or above minimum specifications, more system resources were needed for better usability. In terms of hardware, VNS should be run on a system having at least 1 gigabyte of RAM, a 128 megabyte OpenGL video card (nVidia Geforce 5xxx family or above), and at least an 80 gigabyte hard drive. Many consumer computer systems sold currently typically can be purchased with this level of hardware or higher. However, users operating laptops or older computer systems may not have the necessary hardware to run VNS. Upgrading the system to high spec hardware in these cases may be expensive or not possible at all. These higher system requirements may be an important consideration for using VNS and may cost additional money to ensure that they are met.

Another feature of VNS that can be seen as a weakness is its rendering speed. Rendering in VNS occurs from the camera point out to edge of the horizon along the DEM of the landscape. In cases where a landscape covers a large area, the DEM is broken up into several smaller portions for rendering. VNS attempts to optimize rendering speeds by drawing only the portions of the scene that are immediately visible, however in many instances this is not the case. In many cases, VNS processes other partial DEMs and image objects that are not present in the immediate scene. The processing of these unnecessary items can slow rendering due to the application waiting to process the actual information needed to be rendered. Increased time for rendering can slow work if many previews of a visualization are needed while components are being edited. Increased times can complicate the production of animated images as well. With each additional individual key frame scene added to the animation, even more information is accumulated for processing. Times necessary for rendering these sequences can increase dramatically with the addition of more key frames. Even short sequences running up to a minute at 30 frames per second can take up to 72 hours to render.

VNS is a very powerful application capable of performing many different functions. However, many of these functions are quite complex, requiring many steps to carry out. There is a tutorial that explains the basic functions of the application, but many of the more advanced functions and settings are not explained. Likewise, the manual fails to explain them in great detail. This lack of explanation can be a potential problem for new users not familiar with VNS. Users may require additional time to learn the features and experiment with settings to determine their function. Extra time taken to obtain this familiarity can add to the time needed to complete a visualization. An improvement in both the tutorials and documentation included with VNS can help to provide users with more information and better understanding of the application.

ArcScene: Strengths and Weaknesses

When compared to those of VNS, the operating hardware requirements for ArcScene are somewhat lower. The Hobcaw visualization was successfully completed in ArcScene using the same laptop system that VNS failed to adequately perform on. Aside from an initial startup time of about 2 minutes, operations within the application performed quickly once it was loaded. Main project files remained fairly small at only a couple of megabytes in size, and the application appeared to use the available RAM efficiently. Except for opening large attribute tables or doing very complex queries, most operations were executed almost immediately. In addition, rendering within ArcScene was much faster than VNS. For the Hobcaw project, almost 10,000 individual tree points were rendered within the scene. After loading them into memory, tree models were rendered almost immediately with nearly no wait time. Furthermore, the camera viewpoint could also be moved in real time to view the scene from different positions with no additional rendering. Operations such as this were not possible in VNS due to scenes which needed to be rendered every time the camera viewpoint was moved.

ArcScene also provides very good support for producing animated sequences. Animations can be produced in real time using tools within the application. Unlike in VNS where are sequence of key frames are selected, the user is able to freely move around the scene and capture that movement as an animation. There are two modes which simulate different types of movement through the scene; an overhead bird's eye view and a ground view similar to driving an automobile. Both modes provide the user with quick options for moving within the scene at different viewpoints. In VNS, the user must manually change camera options or construct a preconfigured flight path to show a change in viewpoint during the animation. These operations can be time consuming and not as user friendly as the options provided by ArcScene.

While ArcScene performs adequately with less available hardware and has good animation support, one of its most lacking features is the limited realism of image objects within its graphics library. While some of the objects like roads may appear suitable, others such as tree models look very simplistic. Nearly all the tree models are constructed using 2D images rendered along each plane in a 3D view. Such models did not look very realistic or recognizable as specific tree species. Also, when viewed at certain angles, the individual 2D planar images could be seen, making the models look odd. There are also limited options for editing these models as well. Using the included editor, only the overall hue of the model could be changed. Specific sections of the model could not be targeted nor could multiple colors be utilized. Models can be constructed using 3DS Max for use as custom models within ArcScene, however this was beyond the scope of this project. Likewise, there is also a 3rd party utility for ArcScene called PlantTree which allows for the use of bitmap and jpeg files to be used for tree models. However, the functionality of this utility was found to be lacking in the 9.2 version of ArcScene. Several functions no longer worked and using it to manually place tree images quickly used too much system memory.

In addition to the simple image objects, ArcScene is also lacking many of the models that VNS possesses for simulating a realistic environment. There are no clouds, sky, or atmospheric effects available for use. In addition there are only limited options for simulating light sources such as the sun and the presences of shadows. Due to these factors, the skies present in ArcScene visualizations are empty looking. It technically is possible to place a bitmap image as backdrop to serve as the sky; however such an image may not look realistic or change in perspective with a changing viewpoint. Similar to the lack of sky effects, there is also only a small amount of image objects to serve as ground models. There are almost no ground textures; at most there are options to change the color of the surface DEM. Likewise there are also no textures to simulate different ground types, vegetation cover, or water bodies. The lack of these models tends to make ArcScene visualizations look simplistic and unrealistic. Low realism tends to hinder the observer from identifying with the presented scene. This lack of scene identification can make the visualization less effective, the observer may not be able to draw valid conclusions from the information being presented.

CHAPTER FIVE

CONCLUSION

As demonstrated in this study, wildfire visualization is possible using Visual Nature Studio. Functions in the application allowed for high quality tree models and flame models to be used to create a realistic scene. Editing the tree models and ground textures allowed the effects of the fire to be illustrated both in the tree canopy and on the ground. The result was a realistic visualization of the New Jersey pine barrens showing the spread of fire and its effects within the environment. Still frame images were easily created during any point of the fire along with animated views by piecing together a series of key frame images. The large area in which the event took place presented challenges for visualizing the total extent of the wildfire. High aerial views often had to be used which reduced some of the graphical quality of the visualization.

ArcScene was also shown to be able to perform wildfire visualization to somewhat lesser extent (Figures 3.2 and 3.3). Due to a lack of features, visualizations constructed using ArcScene appear simple and less realistic. There are a lack of image objects to represent aspects of the environment such as the sky, ground textures, and water bodies. Tree models are rather simple and have very limited editing options. Some of the major strengths of ArcScene are its ability to render quickly and produce real time animation. The fast rendering speed allows users to change viewpoints without having to wait for the scene to redraw. Real time animation options also allow users to quickly produce flight and ground based movement throughout the visualization without having to change numerous settings.

Another result of this study is establishing a protocol for visualizing fire using VNS. Such a protocol would provide users with visualization methods without the need of all the original research and investigation needed to establish them. Lab technicians with adequate computer operating skills can use the protocol for visualizing fires not only in New Jersey, but for any other area as well. These technicians would not necessarily need to understand the fundamental theories and mechanics of visualization as long as they possessed the necessary skills to use the various graphic and visualization applications. Having these methods beforehand would potentially allow visualizations to be constructed more quickly, saving both time and money.

Performing similar fire visualization using the two applications allowed for them to be compared and contrasted, showing distinct advantages and disadvantages for each (Table 1.1). Each application was found to have specific differences which gave them different advantages or disadvantages. Visual Nature Studio was found to be very good at creating realistic, high quality scenes. There is ample support for natural environment such as forests, mountains, and deserts. However, there is also support for more urban environments such as towns. ArcScene had simpler scenes with a lower amount of realism, but had real time movement and animation. Such animation could be useful for the simulation of a forest stand cruise. Identifying these advantages can help users to choose the proper application for use based on available resources such as computer hardware, money, and operating ability.

	Visual Nature Studio	**ArcScene**
Support for custom models	Supports JPEGs, Bitmap, PNG and other file formats	Supports 3DS Max file format
Model realism	Limited by model graphic quality	Default images are poor and simplistic
Model editing	Supported by built in editing	Very limited
Environmental effects	Lighting, shadows, reflections, ground textures, etc.	Extremely limited
Sky effects	Atmospheric hazing, clouds, celestial objects	Extremely limited
Rendering Speed	Dependent on complexity of scene, must render each time	Real time
Camera movement	Manual movement and reposition, scene must render again each time	Real time movement and positioning
Animation	Sequence of key frames and points, each rendered separately	Real time flight and ground movement

Table 1.1: Visual Nature Studio and ArcScene comparison.

Using the right application for a project can help to construct a visualization in a timely manner. Less time is spent exploring features that are unnecessary; most of it is spent on aspects crucial to creating a meaningful visualization.

Future Wildfire Visualization Research

Further fire visualization for the immediate future should focus on improving the realism of rendered scenes based on the constraints of the application. For VNS, this can be features such as animated smoke and flames, ground textures from actual fire events, and tree models made from burnt trees in the field. VNS supports the NTSC video format so it may be possible to include video footage of a wildfire as part of the visualization. Improvements in ArcScene include using higher quality tree models constructed in 3DS Max and high quality images to serve as a backdrop for the sky or ground. Likewise, there should also be some observer rating studies done to determine how closely observers are able to identify with a visualization. While rating studies have been done for other types of visualizations, there have been no studies to determine how observers relate to those done using VNS or ArcScene. Working within the constraints of the current applications allows for effective visualization methods to be made without modifying the application. As the applications are improved, these methods can then be applied using the newer technology.

With the recent introduction of multi core CPUs, faster RAM, and more powerful video cards, computing systems have grown even more powerful. As with most software, visualization applications can be improved by taking advantage of this increased power. With more computing potential and faster graphic power, a goal of visualization programs should be the real time rendering of landscape with animated fire and smoke. The program would be able to use high quality graphics to show real time movement of the fire through the environment.

While there is no software application that does everything described, an application that shows great promise is VRFire (Sherman et al., 2007). VRFire is a visualization application being developed at the University of Nevada which uses the FARSITE model to control fire visualization. Analysis is performed to determine the location of the flame front. When combined with landscape and vegetation data, the application is able to determine vegetation within the flame front zones and render appropriate tree models, flames, and smoke as necessary. When areas of flame front are combined for the intervals over the entire fire, the visualization is able to display burned areas in real time. VRFire has the advantage of running on an open source platform of Suse Linux and using open source graphical software. The application runs on a current Opteron CPU based system running an nVidia Geforce 6800 GT graphics card. Output can be displayed to a wide variety of display outputs, such as standard computer monitors to a display screen that interacts with a virtual reality head and wand tracking unit. Currently, VRFire suffers from problems such as limited graphical details and a simplified view of the flame front. However, these problems are being improved so that they accurately represent features that exist in nature.

Improving applications such as VRFire allows the software to take advantage of more powerful computer hardware. With increased power, more possible features such as real time rendering and higher quality images can be made part of the application. As visualizations incorporate more realistic and higher quality images in real time, they can begin to more effectively represent events that occur in nature. With a higher accuracy of representation, observers are more able to identify with the scene and draw conclusions from it. Conferring more data to observers makes visualized scenes more useful and important tools for exploring data or natural processes.

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