COMPUTER VISUALIZATION OF FOREST COVER CHANGE: HUMAN IMPACTS IN NORTHEASTERN KANSAS AND NATURAL DISTURBANCE IN YELLOWSTONE NATIONAL PARK

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ABSTRACT

The merging of remote sensing, GIS and visualization techniques was applied to demonstrate the potential for realistic computer visualizations depicting the dynamic nature of forested environments. Scientific visualizations can aid in environmental and forest management decision making as a support tool and in landscape ecology to relay the findings of studies. While visualization software and methods have already been developed to recreate natural landscapes, little has been done to investigate the potential for illustrating land cover change through temporal data acquired from the real world.

High resolution imagery and aerial photography in conjunction with object oriented image analysis as well as pre-existing land cover datasets were used in the placement of trees and other vegetation in the visualized landscape, providing an accurate representation of reality at various points in time. 3D Nature's Visual Nature Studio was used to construct a variety of realistic stills and animations depicting forest cover change in two distinct settings. Visualizations from Yellowstone National Park focused on the dramatic natural impact of the 1988 fire upon a lodgepole pine forest. In Kansas, visualization techniques were used to explore the continuous human-land interactions between 1941 and 2002 impacting the eastern deciduous forest and tallgrass prairie ecotone. The resulting visualizations demonstrate which techniques and scales are most appropriate for visualizing and exploring change in forested environments. These products provide the means for users, from researchers to resource managers and the public, to demonstrate concepts and develop new hypothesis in these two environments.

INTRODUCTION

Yellowstone

Over 80% of the United States first National Park, Yellowstone, is covered by mountainous forest, composed primarily of lodgepole pine (*Pinus contorta*). Fire is an important natural agent of change in this ecosystem. The large fires of 1988 in Yellowstone National Park demonstrated how dramatically and rapidly the vegetation and consequently the state of an ecosystem can change. The 250,000 ha of burnt forest created a striking mosaic of burn severities on the landscape of the park. Both the ecological and economic impacts of these fires have been significant (YNP 1993; Polzin *et al.* 1993). As the burns have begun to naturally regenerate with lodgepole pine seedlings (Reed *et al.* 1999), the patchwork left upon the landscape has inspired numerous efforts to document and analyze the impacts of this natural disturbance (Stevens, 1990; Renkin and Despain, 1992; Turner *et al.*, 1994; Hardy-Short and Short, 1995).

Northeastern Kansas

The prairie biome, which once covered a vast expanse of the American Midwest, is now greatly diminished (Whitney, 1994). Prior to European settlement, habitats within the prairie's eastern ecotone were an interlocking pattern of forest and prairie, determined largely by the interaction of fire, topography, moisture, soil type, and biotic factors (Anderson, 1990). Human interaction with the landscape has since modified several of these controlling variables. Along the prairie-forest ecotone it is now well documented that woody species can invade grassland habitats that are not burned, grazed, cultivated or mowed (Holt *et al*,. 1995) and it has been suggested that forest expansion into the grasslands of this region has occurred within the last 100 years (Abrams, 1986).

Remote Sensing and Landscape Change

One important method of understanding ecological dynamics, such as natural and human disturbances, ecological succession and recovery from previous disturbances, is the analysis of changing landscape patterns (Turner 1990). Satellite imagery and aerial photography that have been classified by vegetation type provide an excellent source of data for performing structural studies of a landscape (Sachs *et al*. 1998; Fu *et al.* 1994). Simple measurements of pattern, such as the number, size and shape of patches, can indicate more about the functionality of a land cover type than the total area of cover alone (Forman 1995). When fragmentation statistics are compared across time, they are useful in describing the type of landscape change and indicating the resulting impact on the surrounding habitat (Brandt *et al.* 2000). The areas of land cover change between images can also be compared to landscape characteristics to determine if change is more likely to occur in the presence of certain environmental factors. Elevation data have been used to show that forest expansion often favors particular slope ranges (Knight *et al*. 1994) or aspects (Mast *et al.* 1997). Similarly, soil and stream data have been overlaid upon vegetation data in an attempt to derive factors driving landscape change (Lowell and Astroth 1989). High resolution aerial imagery has also been shown to be effective for extracting individual image objects. This level of classification detail presents opportunities for analyzing landscape change patterns at a structural scale (Gerylo *et al*., 2000).

3D Visualization

It is well established in statistics that graphics, specifically data visualizations, are usually the simplest and most powerful means for communicating results (Tukey, 1977; Tufte 1983). This important concept has been expanded to include the use of visualizations for representing natural landscapes. Computer visualization is increasingly used as a delivery tool for the results of environmental change studies and management plans, especially concerning forested environments (Tang and Bishop, 2002). To determine the appropriate visualization technique, one must consider size of the project area, overall goal of the visualization project, the amount of detail that must be present in the final visualization and the amount and types of data available describing the project area (McGaughey, 1997). Until recently, forest visualization efforts have focused primarily upon illustrating static concepts or the possible outcomes of management actions (Bishop and Karadaglis, 1997; McGaughey, 1997; Buckley, 1998). Recent increases in computer speed and software availability permit forest visualization techniques to be expanded to include the communication of change analysis studies (Stoltman et al., 2002).

Goals and Objectives

The main goal of this work is to demonstrate the potential of computer visualization as a tool for communicating the results of forest cover change studies. To meet this goal, the following specific objectives were outlined:

- Develop visualizations to illustrate three scales, including landscape, stand and plot, of forest cover change research in Yellowstone National Park
- Create rendered stills and animation to represent the dynamic nature of 60 years of forest cover change in Northeastern Kansas

METHODS

Study Area

Yellowstone. Unlike most of the United States, Yellowstone National Park, located in the Rocky Mountains (Figure 1), has nearly all of its original species and ecological processes intact. Because of this, the area offers a powerful sense of wilderness and exceptional research opportunities. Over 80% of the landscape is covered by mountain forests in this 9259 km^2 national park and the average elevation in the park's Central Plateau is about 2377 m. The Central Plateau provides ideal conditions for studying the spectral reflectance characteristics of coniferous forests for several reasons. First, the ecology and succession of the Yellowstone forest have been well documented (Despain, 1990;

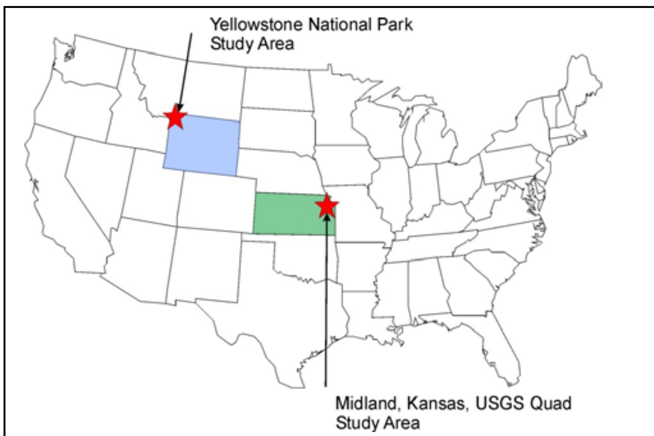

Figure 1. Location of the forest cover change study sites.

Romme and Despain, 1989). Second, much of the temperate Yellowstone coniferous forest occurs as a mosaic of succession stages on extensive, gently rolling plateaus, with easily correctable topographic effects. The 83% of the forest canopy of Yellowstone is dominated by lodgepole pine (*Pinus contorta var. latifolia*), minimizing variations potentially introduced by mixtures of tree species, in particular mixtures of coniferous and deciduous trees.

Northeastern Kansas. The Midland, KS USGS Quadrangle, covering approximately 50 miles^2 falls within the tallgrass prairie and eastern decidous forest ecotone (Figure 1). Located near the geographic center of the conterminous United States, the Midland Quad has a Midcontinental climate. One third of Midland Quad falls within Douglas County, KS, where a 1990 survey indicated that woodlands covered 12% of the county, grasslands (41%), croplands (41%), urban (3%) and water (3%) (Whistler *et al* 1995). In contrast to a natural area or wildlife preserve, this study region was selected specifically because it has heavily felt the impacts of human interaction for more than one hundred years. This factor requires that conclusions drawn about forest cover change in this area are made relative to a human-modified landscape.

Data Collection and Classification

A wide variety of remotely sensed data was used to construct the visualizations of Yellowstone at various scales (Moskal, et al., 2003). At the landscape scale, which covers all of Yellowstone, six different sources of remotely sensed imagery were displayed simultaneously: 30m Landsat TM, 25m SPOT, 5m ASTER, 1m IKONOS, 1m DOQQ and sub-meter Kansas Applied Remote Sensing Program (KARS) DuncanTech Digital Camera imagery (Dunbar *et al*., 2002). For the stand scale of visualizations, GIS polygon coverage of land cover before and after the 1988 fire were acquired from the United States National Park Service. The land cover classification used in these covereages was based on Despain's forest cover type classifications (Despain, 1990). At the plot level, object oriented image analysis methods were applied to high-resolution DuncanTech imagery to extract the exact point location of individual trees, snags and deadfall (Moskal, et al., 2003).

The data set used for the study of Northeastern Kansas forest cover change was more limited in sensor variety than the Yellowstone study, but more rich in terms of temporal coverage. Black and white aerial photography from 1941, 1954, 1966, 1976 and 1991 as well as color infrared photography from 2002 were collected for complete coverage of the Midland, Kansas USGS Quadrangle. After georectifying all dates of the imagery, Definies eCognition was used to classify the photography using an object-oriented approach. The object based classification used by eCognition allowed the spectrally poor black and white imagery, as well as the color infrared imagery, to be classified into forest/tree cover, non-forest, roads/building structure and water classes (Figure 2).

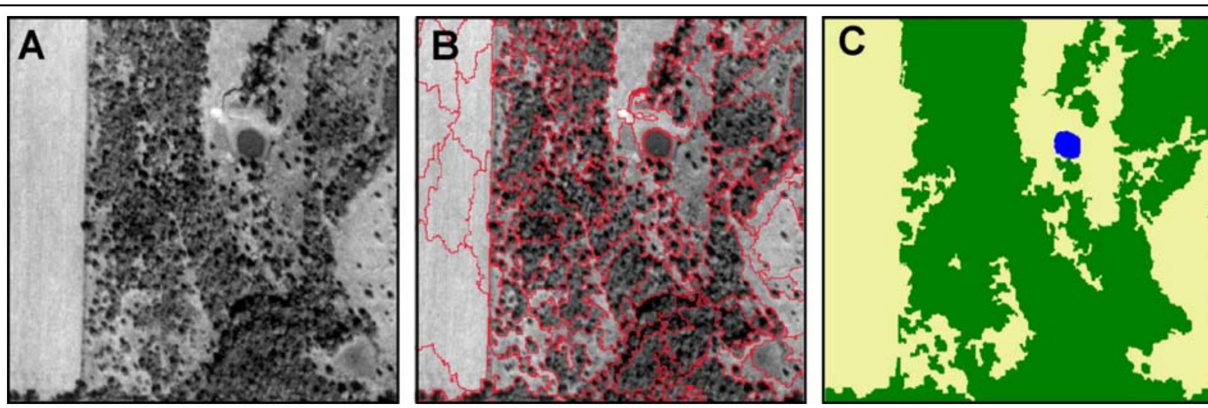

Figure 2. Classification of thee cover on air photos using the object-based algorithm approach.

Visualization

Visualization efforts to date have focused primarily on meeting the objectives for Yellowstone National Park. While this work only presents a selection of still images, other visualizations, including images and animations, may be acquired by contacting the author or the Kansas Applied Remote Sensing Program. After an exhaustive search, 3D Nature's Visual Nature Studio (VNS) was chosen as the most appropriate photo-realistic visualization software package for exploring forest rendering techniques at a variety of scales. Along with its lifelike rendering ability, VNS was selected for a number of other specific qualities:

- Integration with georeferenced GIS datasets
- Flexibility of land cover type development using "ecosystems" and "ecotypes"
- Use of raster or vector formats to drive rendered vegetation components
- Both motion and time-series animation ability

Visualizations covering the largest possible area, the landscape level, are used primary to provide an overview of the study region and show the general spatial arrangement of landscape elements. The landscape level visualizations for Yellowstone used VNS to demonstrate the image-based visualization approach of draping imagery data over a digital terrain model. An 80m Digital Elevation Model (DEM) of both Yellowstone and the adjacent Teton National Park was used as the base terrain layer. Six remotely sensed image data sets at a variety of spatial resolutions, from 30m Landsat TM to sub-meter digital camera imagery, were then draped upon the terrain using texture-mapping techniques. Finally, GIS layers, such as the Yellowstone park boundary, were inserted to aid in interpretability. Still renders were generated from this project and animations were created using a pre-defined camera flight path in the form of a vector GIS layer. This was the simplest visualization modeling technique where conventional technology can be easily implemented.

Projects designed to relay the overall structure of a functional unit of land cover are termed stand level visualizations. The next stage of visualization used in the Yellowstone effort is a mixed-scale approach, using vegetation objects to visualize forest structure between a landscape and stand level of detail. These visualizations highlight landscape characteristics such as the spatial arrangement of stand types and stand structure. The focus of the landscape/stand level visualizations was the three successional stages of the logepole pine forest: the seedling/regenerating stage, the even canopy 40 to 100 year old stage and the mature forest stage. VNS represents trees, snags, deadfall, ground cover and other vegetation types using image objects taken from the real world. Objects are either placed individually on the landscape or grouped together in associations called "ecotypes." Each ecotype consists of groups of image objects, each with their own height range and density specifications (Figure 3). At the landscape/stand level, where only general land cover classes are known, we used GIS polygon coverages to drive the placement of ecotypes upon the landscape. Pre and post 1988 fire stills and animated visualizations were developed to demonstrate the usefulness of these visual tools in landscape/stand level spatial metrics analysis.

The most detailed stage of visualization is the plot level, where specific changes in stand structure can be illustrated. In contrast to the use of GIS polygons at the stand level, exact locations for trees, snags and deadfall was known at the plot level. For these visualizations, GIS point coverages were used to place individual image objects of various heights upon the terrain. Two 200m^2 study sites were selected for the plot level visualizations. The first site was located in a regenerating forest while the second was selected within a mature forest (Figure 4). In an effort to improve upon the plot and stand level visualizations, we returned to the park in the fall of 2002 to collect image objects specific to Yellowstone and photographs documenting various land cover classes. These datasets allowed the refinement of the ecotypes developed for the various land cover types to more exactly match the living and non-living vegetation objects specific to Yellowstone. (Figure 5)

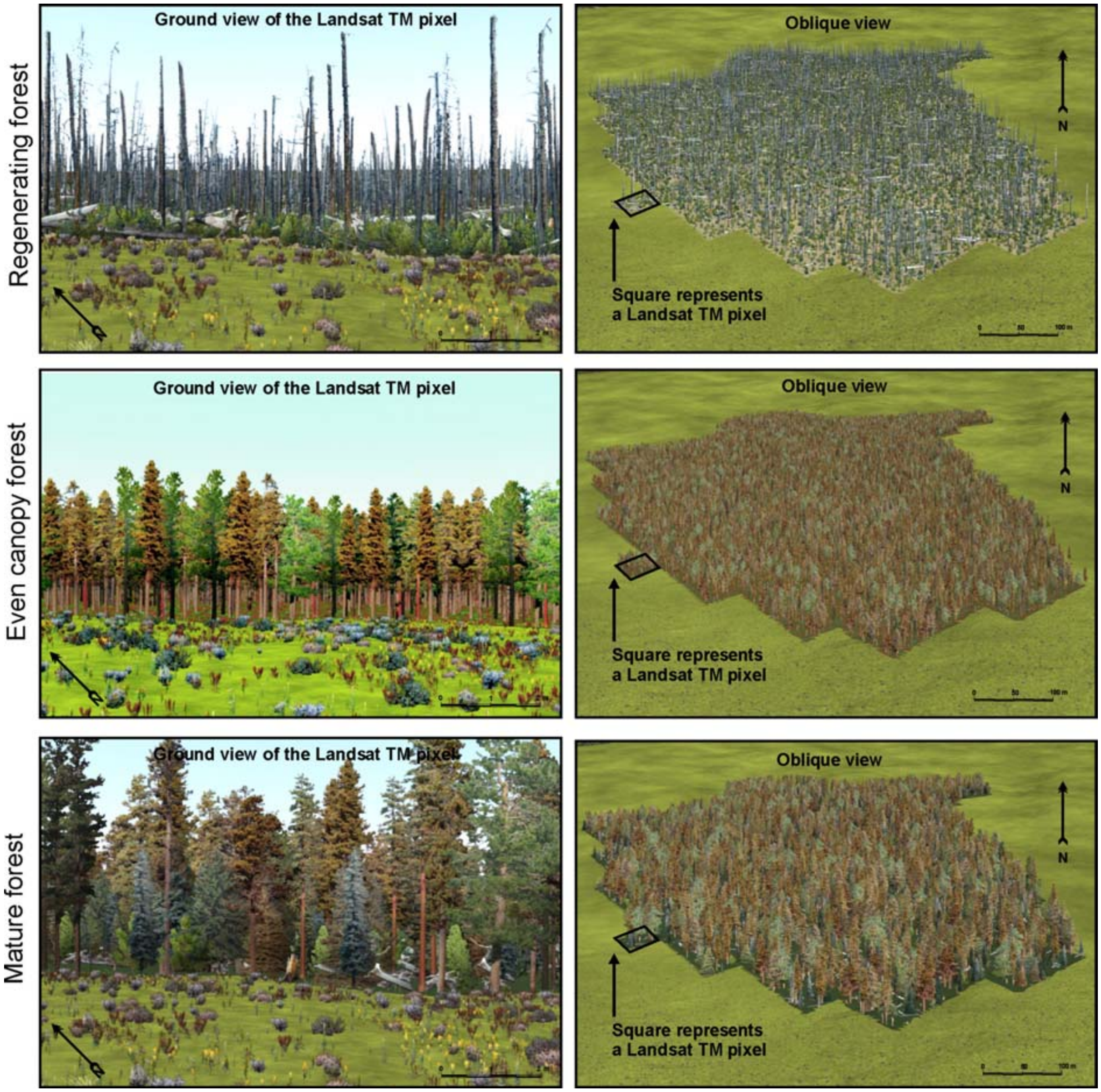

Figure 3. VNS ecotypes representing three successional stages of the Yellowstone lodgepole pine forest.

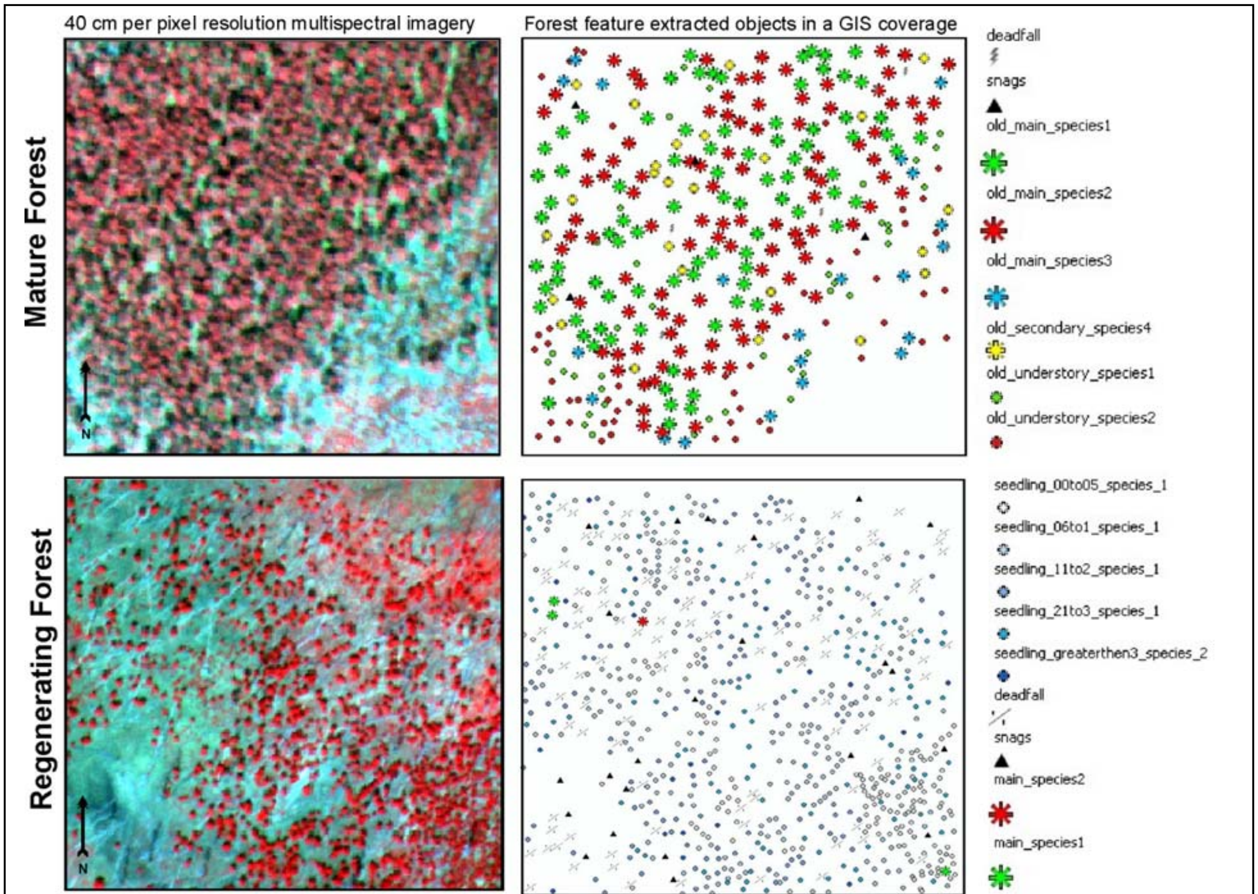

Figure 4. KARS DuncanTech high resolution multispectral camera imagery and derived GIS point coverages for two sites in Yellowstone Lower Geyser Basin.

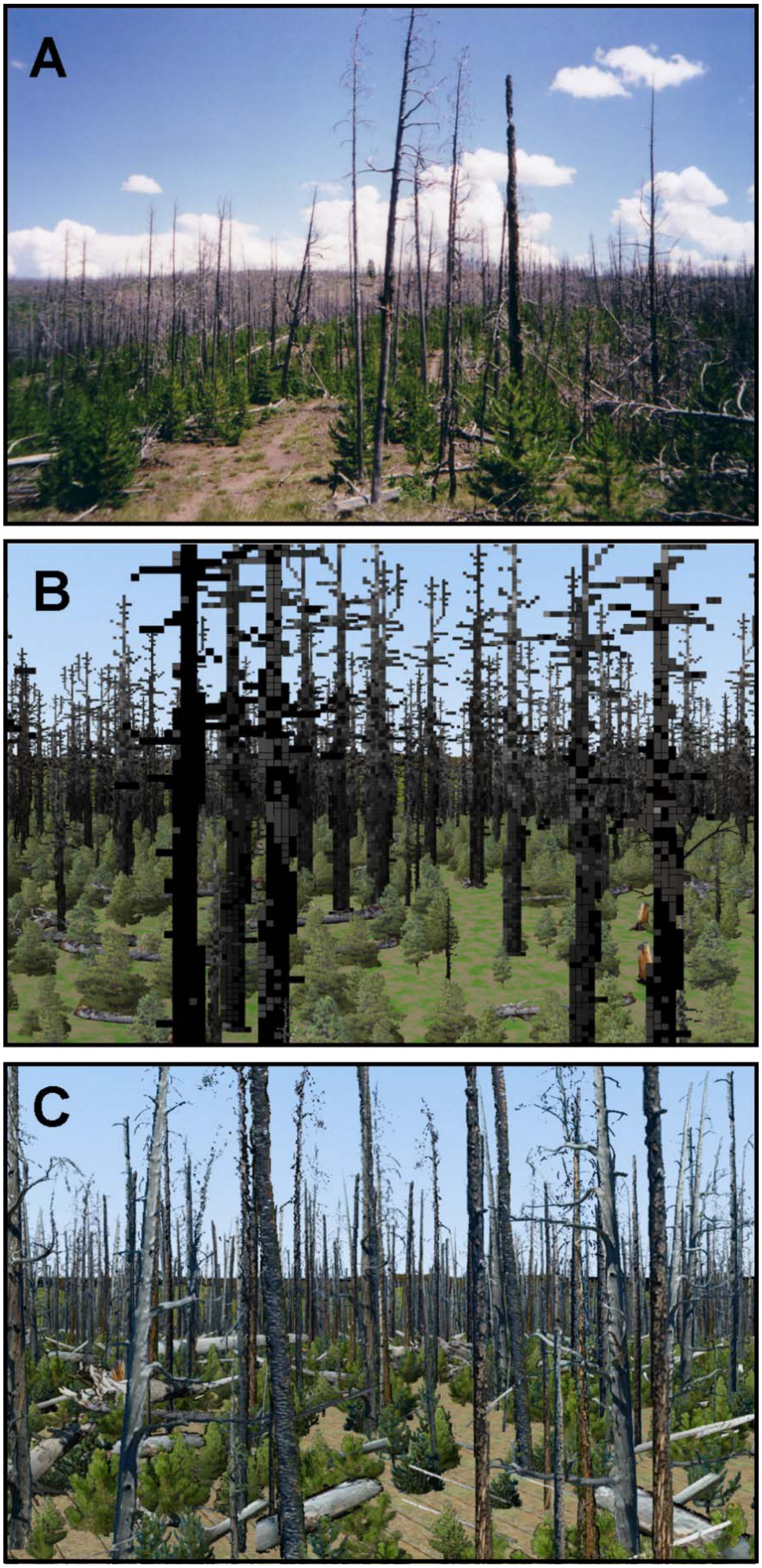

Figure 5. Ecosystem refinement for regenerating forest: a) field photo, b) initial visualization using generic image objects, c) final visualization using image objects acquired in Yellowstone.

The visualizations for the forest cover change study in Northeastern Kansas are in process, thus only a general overview of the methodology will be presented here. The visualization strategies for illustrating the human-impacted forest change in Northeastern Kansas will focus on visualizing the changing tree coverage area from 1941 to 2002, with less emphasis placed on recreating different forest cover types. By visually stacking each year of data atop one another, a preliminary idea of the type of forest cover change visualizations expected for Kansas can be inferred (Figure 6). Once change analysis techniques, such as the generation of fragmentation statistics, change analysis and correlation of change with environmental factors, are completed, visualization techniques, similar to those used in the Yellowstone example, can be employed to effectively communicate the results of this study. Stills will be constructed at various scales to illustrate the areas of forest cover for individual years and the regions of change or stability between specific years. Animations will also be developed to realistically recreate the changing forest cover patterns in this area over the 60 years of available imagery.

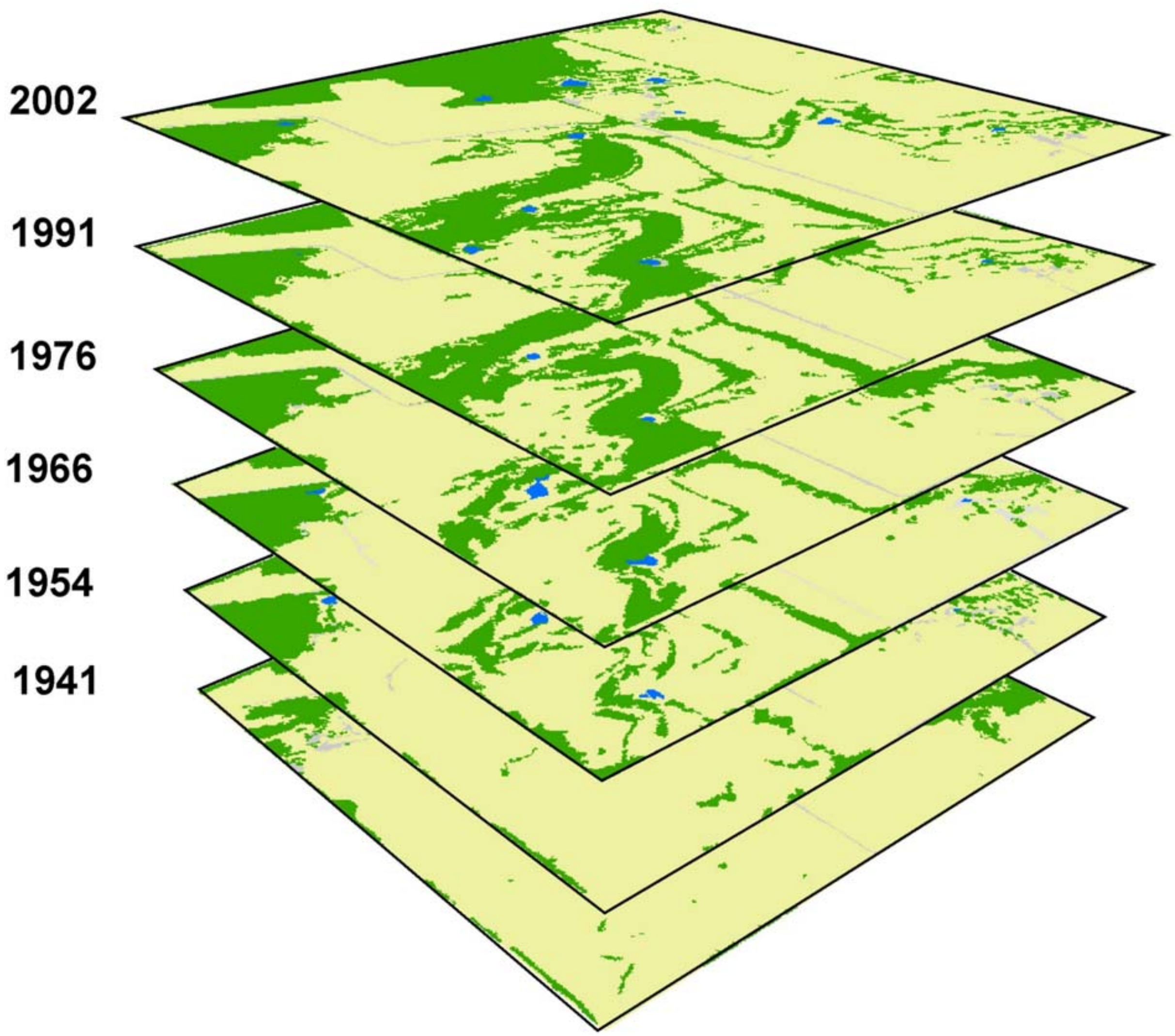

Figure 6. 3D data stack of one section (one square mile in Northeastern Kansas) classified into forest (green) and non-forest (yellow), water (blue) and man-made features (grey).

RESULTS/DISCUSSION

Yellowstone Visualizations

The landscape level image-based visualization incorporates six different remotely sensed data types draped over a digital terrain model (Figure 7). The animation created from the landscape level visualization offers a flyby that places the spatial extent of Yellowstone National Park in context. The flight path was chosen to highlight each of the imagery types available for the park, indicating their coverage extent, spatial resolution and spectral characteristics. These types of visualizations, both stills and animations, help to orient those unfamiliar with the study area, illustrate properties of remotely sensed data and provide a general sense of land cover structure.

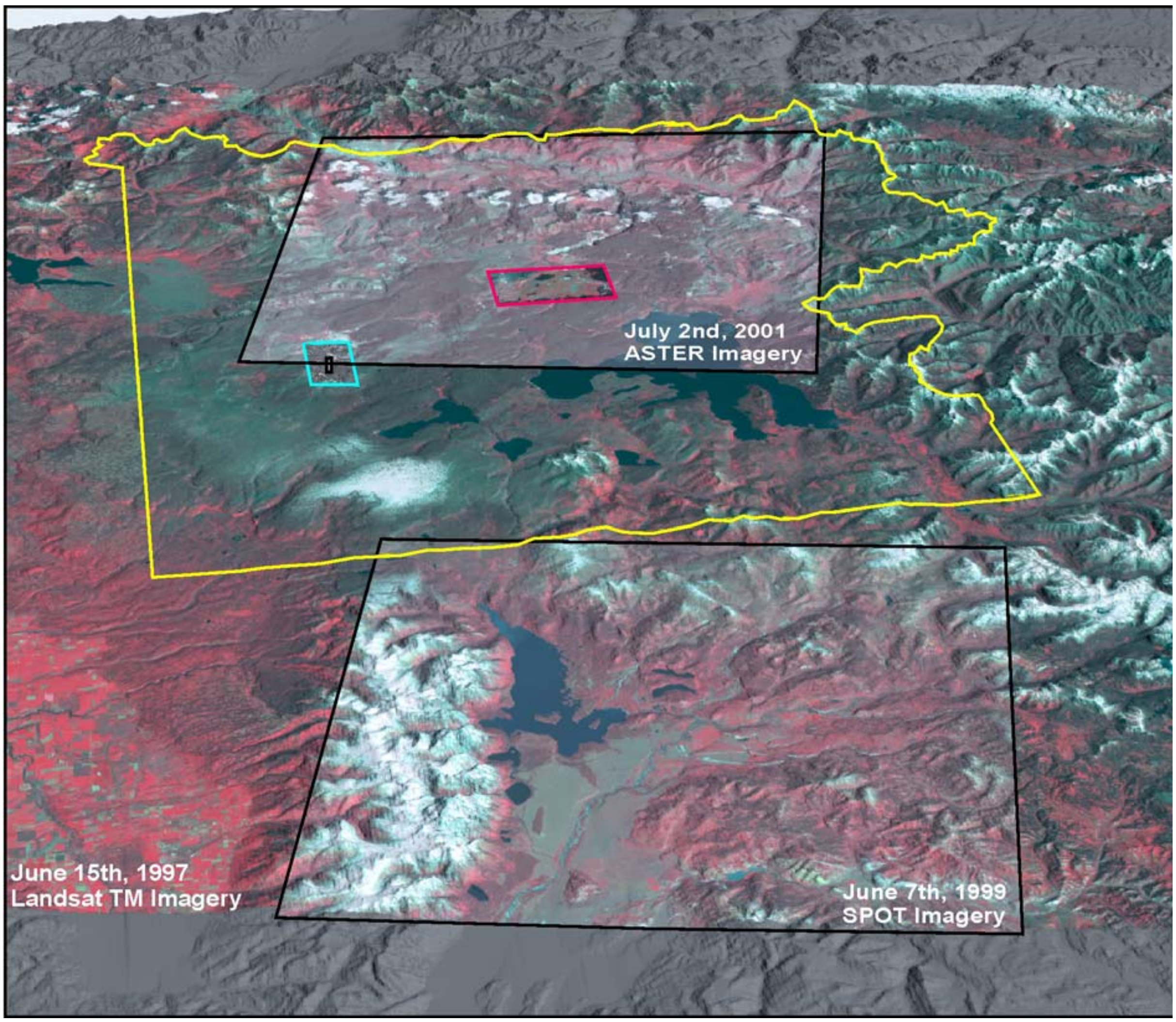

Figure 7. Landscape level visualization, The Yellowstone National Park boundary is delineated in yellow, the IKONOS imagery is shown in red and DOQQ image in light blue.

Visualizations at the landscape/stand level of detail are useful in communicating the overall structure of land cover patterns and land cover change. Landscape metrics and spatial analysis are becoming widely used in many aspects of ecological assessment and resource management. By quantifying the pre and post 1988 landscape using various spatial metrics, comparisons can be made between the temporal representations of the landscape. Summary tables can quantify differences representing change in the forested landscape, but indicating the levels of change is often difficult. Visualizations are used to support the content of landscape metrics analysis making the information more accessible to forest managers, ecologists and the public. While the stills shown in Figure 8 help to illustrate a snapshot of a stand level view, animations created for this project can further acquaint the viewer with the landscape structure by means of motion simulating flight or ground based movements.

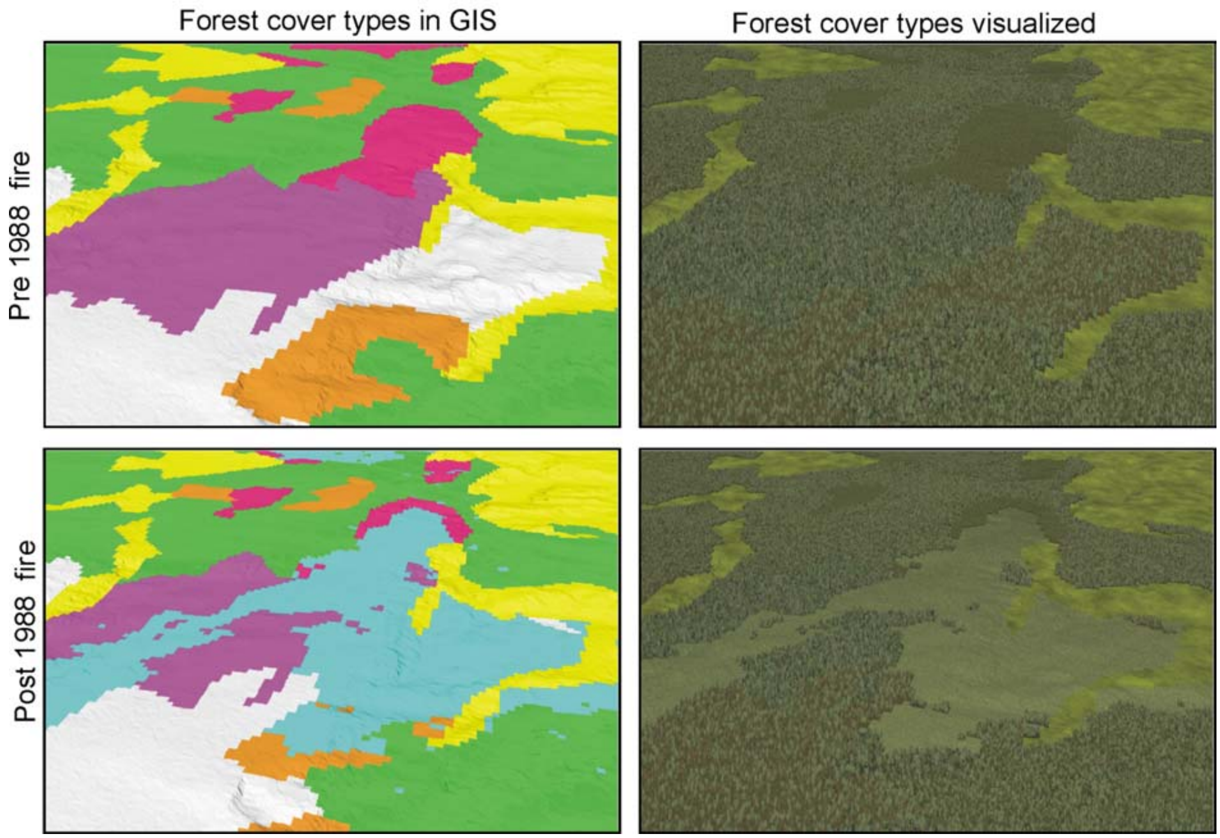

Figure 8. GIS polygon view of the landscape compared to a view using rendered forests.

The finest level of detail of a forested cover type can be illustrated with plot level visualization, which highlights unique structural characteristics of a specific forest plot. More precise changes in forest composition and structure are presented at this scale. The plot level visualization in this study demonstrates the ability of object oriented feature extraction to describe relative position and size of individual trees and other landscape components. While a GIS provides the means to catalog and display the spatial position of point features representing trees in the plot, only someone intimately familiar with both the forest ecology and GIS symbology can comprehend what is physically on the ground. In contrast, the visualized representation of these plots clearly communicates the forest structure, including species/object type, location and size, in a simple yet powerful manner (Figure 9).

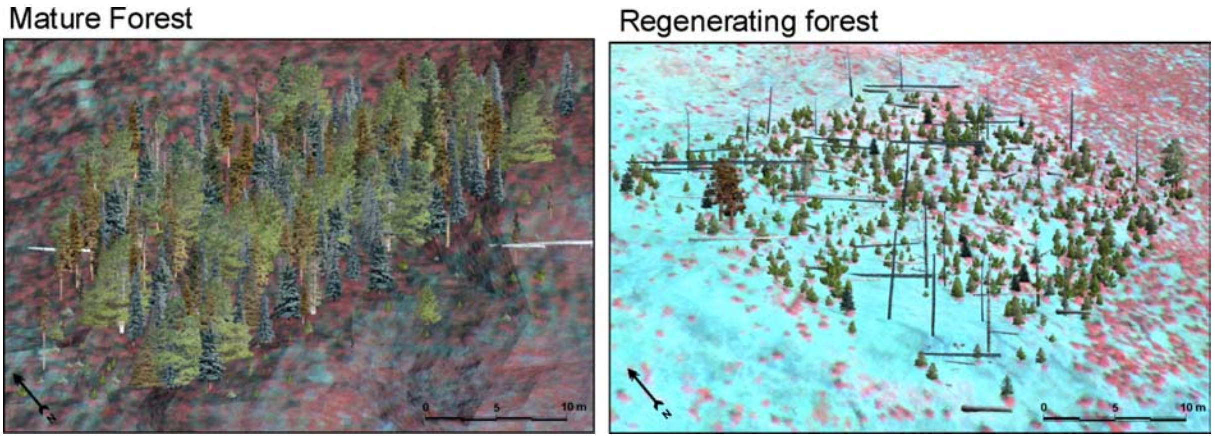

Figure 9. Plot level visualization based on uniquely identified image objects.

CONCLUSIONS

These examples prove the validity of 3D computer visualizations for illustrating various types forest cover change in two distinctly different environments at several spatial scales. The purpose of examining two different types of forest cover change was to demonstrate the applicability of these visualization techniques to a wide array of forest research areas. Any remote sensing based research resulting in forest compositional or structural classification, forest modeling, or forest management plans could benefit from the ability to more clearly relay results to intended audiences. As well, these same techniques could be employed to communicate the results of any other ecological studies such as the impacts of prairie burning, historical landscape recreation, or agricultural management practices. Future efforts will focus on refining the animation techniques used to relay forest cover change in these two environments by investigating new methods for displaying landscape structure information as it evolves through time.

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