P1.15 GIS FOREST INVENTORY AND EVALUATION IN THE WAKE OF CLIMATE CHANGE

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1. INTRODUCTION

Because climate and vegetation are so strongly associated, it is assumed that the forecast rapid changes in climate will affect plant distributions and alter the makeup of forest communities. For example, climate change could cause regional wind patterns to shift, which would be accompanied by an increase in wind speed intensity. Such shifts could impact existing rain shadow effects in some regions causing more precipitation on the windward side of mountain ranges while creating even drier conditions on the leeward sides. Fire patterns are likely to be altered as well, which could affect a variety of plant species, even those that are fire resistant or require the presence of fire to regenerate. History has shown that most species respond individually to climatic change and not as communities. Those individuals that have the ability to migrate likely will do so, resulting in a number of new associations. In addition to differences in migration rates, community types will be altered and new associations will be created due to changes in disturbance regimes and competition.

To inventory, evaluate, and mitigate the damage to forest communities as a result of climate change, researchers require the use of spatial analysis tools such as Geographic Information Systems (GIS). This research examines several case studies of GIS applications related to forests and climate change. Although GIS is a proven instrument for assessing environmental impacts on forests and woodlands, numerous challenges remain. For instance, when developing GIS models urban forests tend to be treated as isolated elements, which can lead to miscalculations in predicting landscape changes. And while there has been substantial improvement in simulating disturbances within landscapes, it is presently difficult to model global vegetation change at the landscape scale. Despite these and other shortcomings, the results of this research suggest that a well-designed GIS can serve as a frontline defense against environmental impacts associated with climate change.

2. BACKGROUND

According to the Intergovernmental Panel on Climate Change (IPCC, 2007) established in 1988 and made up of more than 2000 scientists from over a 130 countries, most of the rise in average global temperatures since 1950 is very likely due to the observed increase in anthropogenic greenhouse gas concentrations, and an analysis of data since 1970 reveals that anthropogenic warming has indeed had a discernible influence on natural systems across all continents and most oceans. A global warming increase of 1 to 3 Celsius degrees by the year 2100 will put the most stress on those systems that are already affected by pollution, thus increasing resource demands and non-sustainable management practices.

Locations from the equator to the poles are forecast to experience higher temperature profiles accompanied by severe droughts, rainstorms, heat waves and floods (Stevens, 1998). The arctic and temperate latitudes will endure warmer and stormier winters while summers will be hotter with less precipitation. Regional factors such as variations in hills, lakes, coastlines, and soils affect local climate, so that some areas could experience even higher temperatures than the mean global changes (Schwartz, 1992). Factors such as ground-level air temperatures, relative humidity, exposure to winds, persistence of snow, length of frost-free growing season, and duration and intensity of sunlight vary considerably. However, an increase in temperature of 1 to 3 Celsius degrees over the next century would be equivalent to shifting isotherms toward the poles from 250 to 500 kilometers (Kates, 1997). Thus, higher latitude locations can expect to be exposed to higher increases in temperature.

3. NEGATIVE EFFECTS

Unlike earlier climatic events, such as those following the last Ice Age, which slowly took place over long periods of time, these forecast variations are expected to occur suddenly with the average rate of warming probably greater than any seen in the last 10,000 years (fig 1). Many species attempting to adapt to this rapidly changing climate will be forced to migrate at rates of speed beyond their abilities, which may be the greatest of all potential threats to biodiversity.

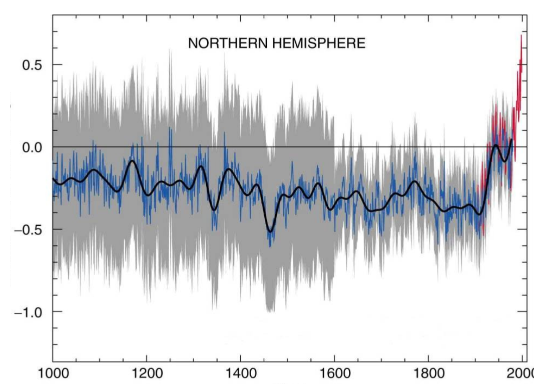

Figure 1. Departures from 1961-1990 normal

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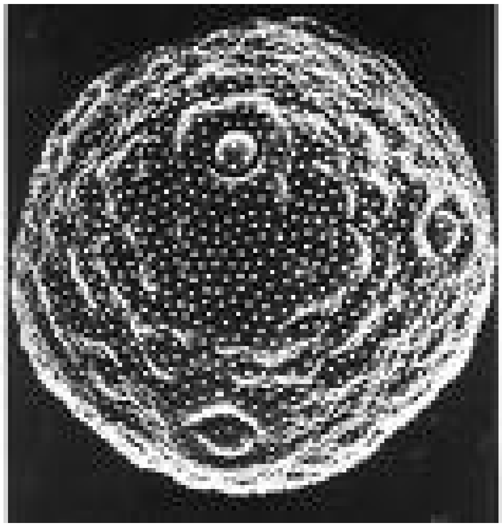

Figure 2. Pollen grain

Evidence from the fossil pollen record reveals the migration rates of various species since the end of the last glacial period (fig. 2). According to a benchmark study by the Environmental Protection Agency (1989), beech and maples migrate at a rate of 10 to 20 km per century, hemlock migrate at 20 to 25 km per century, and pine and oak species migrate at 30 to 40 km per century. Other research suggests that within the next century plant species may be forced to shift as much as 500 km, which is well beyond the migration rates of many species (Russell and Morse, 1992).

Due to temperature increases, the limited availability of water, and other environmental factors, entire forests may disappear, and new ecosystems may take their places. Also, a global average of one-third of the existing forested area could undergo major changes in broad vegetation types with the greatest changes occurring in high latitudes. Both plant and animal communities at high elevations and in high latitudes may have no place to migrate and could be lost completely. Alpine ecosystems are thought to be particularly sensitive to climate change largely due to their low productivity, tight nutrient cycling, and their position at a limit for many plant processes (Walker et al., 1993). Research that spanned a 125,000-year record of the forest/steppe border along the eastern Cascade Range of the northwest United States, reports climatic variations are the primary cause of regional vegetation change (Whitlock and Bartlein, 1997). Additionally, a study analyzing 19 isolated mountain peaks in the U.S. Great Basin, predicts a loss of 9 to 62 percent of the species currently found at these locations based on a temperature increase of 3 degrees Celsius (McDonald and Brown, 1992).

An intensive analysis to determine the effect of climatic change on 15,000 known native vascular plant species found in North America was conducted by the Nature Conservancy. The researchers assumed that a doubling of carbon dioxide would lead to a 3 Celsius degree increase in global temperatures and based the study on the climatic envelope or maximum and minimum mean annual temperature that each species experiences in its current distribution (Kutner and Morse, 1996). The climatic envelope of each of the 15,000 species was compared to the projected rise in average annual temperatures. The researchers found that approximately 7 to 11 percent or some 1,060 to 1,670 of the species under investigation would be beyond their climatic envelope and at risk for extinction. States in the southeast are projected to have the greatest loss with 25 percent of Florida's flora at risk. This may be due to the number of Appalachian Mountain species in these states that are already at their southern range limits. To put these finding into perspective, during the last two centuries in North America only 90 plant species are believed to have become extinct.

Rare species, which make up approximately 27 percent of North America's flora, were especially at risk with 10 to 18 percent threatened with extinction while only 1 to 2 percent of the more common species were considered endangered. In order to determine the potential for migration in the event of global warming, a dispersal-ability scale was calculated based on full data availability for 8,668 species. The scale takes into account factors such as pollination by wind, dispersal by birds and insects, and generation time with most species having an intermediate dispersal potential. The analysis reveals that in a 3 Celsius degree global warming scenario those species with characteristics that limit long-range dispersal would suffer the greatest risk. Additionally, plants that require specific habitat such as wetlands would also be threatened. While the Nature Conservancy's model relies primarily on temperature and does not take into account a number of other environmental factors, it does represent a general picture of the impact climatic change could have on the flora of North America.

Boundaries between forest and tundra ecosystems as well as tree lines are expected to advance in altitude and latitude in response to climate warming. Danby and Hik (2007) examined recent tree lines at 6 sites in the Canadian Yukon and found that tree line elevation increased significantly during the early to mid-20th century. Kaplan and New (2006) reveal that a 2 Celsius degree increase in global temperatures would raise the mean annual temperature over the Arctic between 3.2 and 6.6 Celsius degrees causing the tundra ecosystem to move northward reducing dwarf-shrub tundra habitat by 60 percent (fig. 3).

Figure 3. The tundra biome

Most European regions can anticipate being negatively affected by climate change, which will pose challenges to many economic sectors. Global warming is likely to amplify regional disparities in natural resources with the vast majority of ecosystems having difficulty adapting to climate change. Rebetez and Dobbertin (2004) report that Scots pine stands in the inner-alpine valleys of the Alps are dying off, and nearly 50 percent of the Scots pine population in Switzerland has already perished since 1995 due to the fact that Switzerland's temperature has increased at more than twice the global average with most of the warming taking place during the last 20 years. An analysis of the response of alpine plant species distribution to various climatic and land-use scenarios found that alpine plant species with restricted habitat availability above the tree line will experience severe fragmentation and habitat loss (Dirnböck, 2003). The future threat to the forests of Europe due to climate change is predicted to be highest in Scandinavia and Eastern Europe (Cassel-Gintz and Petschel-Held, 2000).

The Northern forests that cover much of North America, Europe, and Asia, should be getting greener. Over the past century temperatures have gone up and the length of the growing season has increased, nearly doubling in sections of Alaska. With carbon dioxide on the rise, plants should be thriving. However, Goetz et al. (2005) tracked changes between 1982 and 2003 and found the forest was getting browner instead of greener as expected. Angert et al. (2005) tracked the health of forests along the interior of Alaska from 1982 to 2002 and noticed that after 1994, the carbon dioxide uptake declined during the growing season, hinting that forest growth had slowed during the past decade.

Numerous studies have verified that tropical deforestation has an influence on local and regional climate and could very well play a role in global warming. Palm et al. (2004) suggest that 25 percent of the net annual carbon dioxide emissions are the result of clearing tropical forests. Gbetnkom (2005) reports on deforestation in Cameroon and the associated negative impacts including drought, desertification, and the disappearance of plant and animal species. Fearnside (2005) states that the rate of deforestation in Amazonian has rapidly increased since 1991 with 70 percent of the clearing due to cattle ranching, which has led to a decline in biodiversity, weakening of the hydrologic cycle, and enhanced global warming.

Seasonally dry and tropical regions will experience decreased crop productivity with local temperature increases of just 1 to 2 Celsius degrees while increases in temperature and associated decreases in soil water are projected to lead to a gradual transition from tropical forest to savanna in eastern Amazonia by the middle of the 21st century. Notaro and Vavrus (2007) conclude that additional global warming is expected due to the disruption of the hydrologic cycle through reduced evapotranspiration, which will result in drying and reduced forest cover over Amazonia, South Africa, and Australia. Forestry production is projected to decline over much of southern and eastern Australia and over parts of eastern New Zealand due to increased drought and fire by the year 2030 (IPCC, 2007).

4. GIS FOREST APPLICATIONS

The principal advantage of a GIS is its ability to allow the user to perform a spatial analysis, which can be described as the investigation of the locations and shapes of geographic attributes and the interactions between these features. Spatial analysis is essential for determining site suitability and potential, for approximating geographic relationships, and for deducing and comprehending the problems of place. In short, spatial analysis allows one to address those issues associated with location. GIS is a highly effective information and communication technology due to its power to graphically convey knowledge through the universal language of maps. The first modern GIS, the Canadian Geographic Information System (CGIS), was developed in the early 1960s to inventory Canada's natural resources and is acknowledged as a milestone in the development of GIS. The CGIS classified land according to its capability for forestry, agriculture, recreation, and wildlife, and many of the GIS terms and concepts used today originated with the CGIS. The Canadians understood that in order for the CGIS to be an effective environmental tool, accurate and relevant data must be incorporated into the system. The success of the CGIS is evidenced by its continued operation today in mitigating pollution, managing resources, and in land-use planning (Heywood, 1990).

In order to examine detailed spatial environmental data, satellite imagery was integrated with a GIS for a region in northern Wisconsin, which allows an assessment of changes in the forest landscape over time (He et al., 1998). Another GIS was developed to assess the response of alpine plant species distribution to various climatic and land-use scenarios and found that alpine plant species with restricted habitat availability above the tree line will experience severe fragmentation and habitat loss (Dirnböck, 2003). In Munich, Germany, a GIS was utilized to examine the spatial pattern and environmental functions of the urban forest linking environmental planning and urban forestry with general land-use (Pauleit and Duhme, 2000). A GIS analysis of vegetation structure with forest functions and value in Chicago, Illinois, revealed that local urban forests remove 5575 metric tons of air pollutants and sequester approximately 315,800 metric tons of carbon annually (McPherson et al., 1997).

Figure 4. Chicago urban forest

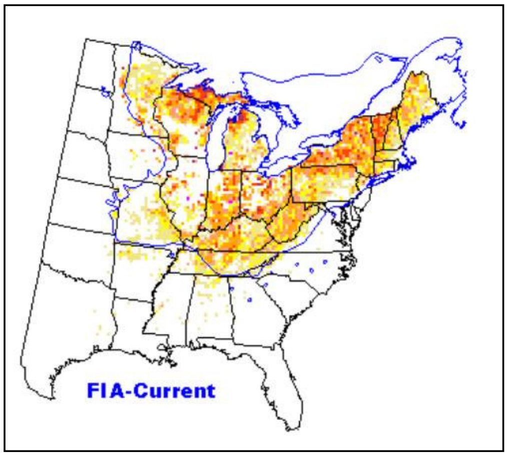

Figure 5. Current sugar maple distribution

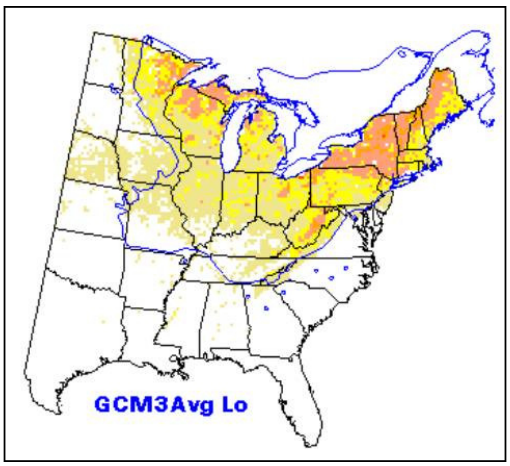

Figure 6. Low impact sugar maple distribution

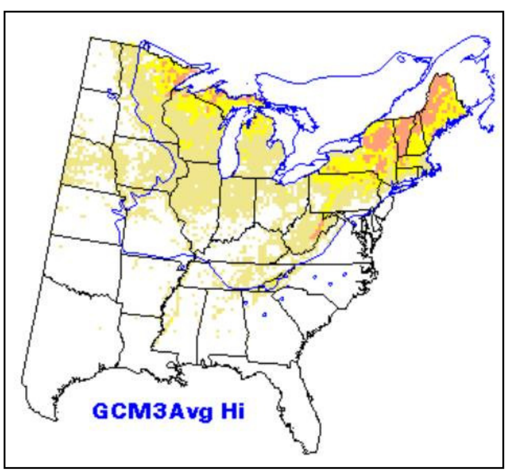

Figure 7. High impact sugar maple distribution

In Chattanooga, Tennessee, a practical GIS was created to map tree locations, and track the type and size of every tree along city streets and in downtown parks in order to maintain a database of tree size and health conditions (Brown, 2003). And In a unique approach to GIS-based modeling, researchers found that the future threat to the forests of Europe due to climate change is predicted to increase in Scandinavia and Eastern Europe (Cassel-Gintz and Petschel-Held, 2000).

Tree data obtained from more than 100,000 plots from the U.S. Forest Service's Forest Inventory and Analysis (FIA) Program for eastern North America representing data for nearly 3 million trees were used to develop a *Tree Species GIS Atlas* to assess the potential response to several scenarios of climate change. The GIS Atlas examines 134 species at 20 km resolution to generate a modeled future habitat based on the output average of three Global Circulation Models (GCMs). The scenarios are the latest generation of numerical models that couple atmospheric, ocean, sea-ice, and land-surface components to represent historical climate variability and estimate projected long-term increases in global temperatures due to human-induced emissions.

Figure 5 depicts the current spatial distribution of sugar maples based on the GIS Atlas. Figure 6 is a GIS of the modeled spatial distribution of sugar maples based on minimal projected temperature change resulting in low impact on the species. Figure 7 represents the high impact on sugar maples of maximum temperature increase projections. The GIS reveals that under this scenario, the density of sugar maples is greatly reduced although its range slightly increases.

5. SAVING FORESTS

Because forests exert such a strong influence on the environment, they are a critical element in mitigating climatic change due to their ability to slow the rate of greenhouse gas emissions. Several options for reducing carbon dioxide through the use of trees are available which include curbing deforestation, establishing reforestation projects, enhancing management and harvesting techniques, and maximizing urban forests. It is widely accepted that protecting existing forests and planting new forests can help reduce the greenhouse effect, and a number of multi-disciplinary mitigation options revolving around forests are surfacing as researchers collectively consider the threat of global warming.

Many groups have proposed forest management as a simple way to restrain the increase of atmospheric carbon dioxide and offset global warming. To examine whether forest management is a suitable means of controlling global warming, Barford et al. (2001) conducted a decade-long study of carbon exchange between the atmosphere and a 60 year-old northern red oak forest by measuring how much carbon the trees and soils stored and how much they released.

The types of tree species in the forest, their growth rate, and the age of the forest all affect carbon uptake. For example, mature trees store less carbon and remove less carbon dioxide from the atmosphere. The number of dead trees also affects carbon balance because as a tree decays, it releases some of its stored carbon back into the air. The researchers suggest that forest management can help mitigate global warming by controlling carbon exchange, but it is a complex process with numerous factors to be considered.

Many of the deforested areas of the world could once again support vegetation under proper management techniques such as the creation of tree plantations or by allowing natural vegetation to regenerate through techniques such as wildfire suppression. One of the main reasons for preserving tropical forests is their role in regulating climate and hydrological cycles because tropical forests are involved in the constant exchange of large quantities of energy that takes place between the biosphere and the atmosphere. Tree plantations can have rapid growth rates and yield substantial benefits including an economic return for local people. Streed et al. (2006) report that small-scale reforestation in Costa Rica with mixtures of native species have proven to be financially profitable both for investors and farmers. Bangladesh has a huge potential for reforestation, and according to Shin et al. (2007) replanted forests there could store an average of 92 tons of carbon per hectare.

Jim and Liu (2001) detail the rapid growth and expansion of tree management projects in China, which in addition to sequestering carbon dioxide emissions have an important impact on the mental and physical well-being of local residents. Zhang and Song (2006) report China's forest cover increased from 9 percent in 1949 to 18 percent in 2003. Fang et al. (2001) examined 50 years of forestry data and found that beginning with the 1970s, the average carbon density of planted forests in China increased from 15 to 31 megagrams per hectare. In short, forest restoration appears to be a means of improving ecosystem functioning, ecological and economic resilience, and human livelihoods (Lamb et al., 2005).

However, while reforestation is a popular strategy, it cannot be effective if it legitimizes the continued destruction of old-growth and pristine forests which are rich ecosystems and have an established biodiversity base that naturally maintains the environment. Reforestation also cannot be viewed as a quick fix by the logging industry and nations with large forests interests, if it does not lead to or promote actual emissions reduction. A better approach is to slow the rate of deforestation, which in turn is an effective way to reduce carbon losses from forest ecosystems. With increasing pressure from expanding populations and the use of natural resources, developing countries have to be integrated into a more comprehensive incentive framework that rewards forestry conservation, sustainable forest management, and reforestation (Streck and Scholtz, 2006). As Lu et al. (2006) note, incentive approaches for citizens in the developing world are indispensable for effective conservation and successful management in protected areas.

6. CONCLUSION

Global warming and climate change are among the most serious environmental problems the world community faces today. There is clear evidence that human activities are involved in the process, largely through the production of greenhouse gases. Deforestation contributes to the increasing amount of carbon dioxide in the atmosphere and is influencing climatic change at the local, regional, and global scale. Because climate plays such an important role in the distribution of plant species, the predicted global and regional climatic changes will likely affect a variety of existing vegetation patterns. Some species will migrate forming new associations while others will be lost completely.

A pragmatic and economical place to start restoring the balance of our global carbon cycle is in our forests. Researchers have identified the coastal redwood and Douglas fir forests of the U.S. Pacific Northwest as having the greatest capacity for increased carbon sequestration of any trees in the world. With proper stewardship, forests will continue to provide carbon sequestration in addition to wood products and other benefits, such as fish and wildlife habitat, biodiversity, clean water, and recreation opportunities. Without good forest stewardship, we are likely to lose the battle with global warming and along with it, the myriad benefits the forests provide.

GIS is generally acknowledged as an influential instrument for modeling and simulation. However, there are a number of factors related to GIS visualization that must be considered. Foremost among these are the spatial data required to generate an accurate forecast. Longitudinal data are necessary to establish past and future long-term patterns and trends. Yet, appropriately extensive climate records might not be available for a given location, which is one of the problems associated with trying to resolve the effect of global warming on urban forests. In summary, GIS is an established instrument for evaluating the negative effects of global warming on forests. However, many challenges continue in the quest to confront climate change.

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