Information Technology Approaches to Forest Management

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Abstract: The majority of the world's forests occur where there is a dry season long enough to affect a seasonal change in the forest community. The seasonal forest may include evergreen, semi-deciduous, deciduous trees, or some combination of these. Local differences in soil or other site characteristics often determine which community persists. Since the seasonal forests exist where there is seasonal precipitation, the character of the forest is closely associated with the length of the rainy season. As the length of the rainy season decreases, the density of the canopy decreases. If the global climate system warms and prolonged drought gives way to desertification, entire forests are likely to disappear. This can lead to a negative feedback loop because forests are a critical element in mitigating climatic change due to their ability to slow the rate of greenhouse gas emissions. Fewer forests will result in an increase in carbon dioxide levels. To counter this negative scenario, forest researchers are turning to options for reducing carbon dioxide including reducing deforestation, reforestation projects, establishing urban forests, improved forest management, and enhanced harvesting techniques. Among the new technologies in these endeavors are Geographic Information Systems (GIS). This study analyzes various afforestation and reforestation projects and examines the value of conservation and restoration as a means of mitigating climate change while improving local ecosystems and economies.

Key-Words: GIS, reforestation, afforestation, management, climate change, carbon dioxide, sequestration

1 Introduction

There are many definitions of forest because of the many varieties of forest communities. Put simply, forests include those formations in which trees are the prevalent plant form. Among the factors that determine the distribution of flora are radiant energy, soils, parent material, slope, moisture availability, and other biota. Climatic factors are a major determinant in the distribution of individual species and communities. Where climatic conditions are fairly similar from year to year in terms of temperature and moisture, a fairly distinct mature plant formation has evolved.

The connection between forests and climate is uncontroverted. During photosynthesis, plants produce oxygen while absorbing carbon dioxide, the major anthropogenic greenhouse gas. Animals require oxygen and exhale carbon dioxide. This symbiotic relationship benefits the entire biosphere. However, between 1600 and 1900, nearly half of the forested land in the United States was cleared [1]. Reasons for the continued loss of forests worldwide include an increase in the demand for wood products and clearing land to raise livestock. More than half of the world`s supply of industrial roundwood, which is cut as timber and processed into veneer, sawnwood, fiberboard, paper, paperboard, and plywood, is produced by Canada, the United States, and Russia. With the global population expected to reach 8 billion by the year 2025, the pressure placed on forest products is certain to rise over the next decade resulting in significant losses of forests worldwide.

By the year 2100, global temperatures are forecast to increase by 1 to 3 Celsius degrees, according to the Intergovernmental Panel on Climate Change [2]. The higher temperatures will add another stressor to those forest ecosystems already affected by clear cutting, air pollution, and global demands for beef, palm oil, and fuel wood. These demands, if not factored into planning strategies, could result in the growth of non-sustainable practices. In light of these circumstances, prudent environmentalists are using information technology in the form of Geographic Information Systems (GIS) to help restore old forests, conserve existing forests, and create new forests in an attempt to lower carbon dioxide levels while raising local community living standards.

2 Forest Impacts

The boundary layer of the forest is its canopy, and it is at this level that energy exchanges occur. Some insolation is returned directly to space, and the amount depends on the albedo, or reflectivity, of the canopy layer. In some forests, the quantity varies enormously from season to season. Some energy is trapped within the canopy layer and some penetrates to the forest floor. The amount of penetration is characteristically low, and varies with both the state of the sky along with the amount and type of foliage that exists within a particular biome.

For example, the tundra is associated with the seasonal rainfall areas around the Arctic Ocean and at high altitudes in mountains. It exists where there is a short summer season that is too cool for trees to thrive. The vegetation of the tundra has distinct characteristics that allow it to survive the cold temperatures, wind, and very long physiological drought. Almost all tundra plants are low growing and compact to escape the wind, reduce evaporation, and conserve heat.

The established boundaries between tundra and forest ecosystems are advancing both in latitude and elevation as the climate continues to warm. An increase of 2.0 Celsius degrees in global temperatures would raise the mean annual temperature over the Arctic between 3.2 and 6.6 Celsius degrees resulting in a northward migration of the tundra ecosystem and a 60 percent reduction of dwarf-shrub tundra habitat [3]. Similarly, an examination of six study sites in the Canadian Yukon found that tree line elevation had increased significantly during the early to mid-20th century [4].

One of the few touted benefits of rising carbon dioxide levels has been the projection of enhanced growth of vegetation. However, recent research suggests that northern forests are becoming browner instead of greener as expected [5]. The general health of the forests along the interior of Alaska during the years from 1982 to 2002 has been extensively studied and it has been noted that after 1994, the carbon dioxide uptake declined during the growing season, suggesting that forest growth had actually been reduced [6].

At the other end of the biome spectrum, rainforests are formations in which broadleaf evergreen trees are dominant and the canopy is more or less continuous. Rainforests exist where moisture is abundant during the greater part of the year. Most of the vegetation in these communities is found in the uppermost canopy. The canopy and foliage of the lianas, epiphytes, and parasites are concentrated in the canopy. Beneath the canopy, the understory consists largely of young trees of the dominant species and a ground cover of shade-loving shrubs as well as other lower forms of vegetation. Due to their climatic requirements, these forests are very limited in extent.

Deforestation of rainforests has an influence on local and regional weather and could very well play a role in global climate change. One study suggests that as much as one-quarter of the net annual carbon dioxide emissions worldwide are the result of clearing tropical forests [7]. 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 weakening of the hydrologic cycle, a decline in biodiversity, and enhanced global warming [8]. Likewise, deforestation in Cameroon has led to widespread desertification due to drought along with the disappearance of plant and animal species [9].

The forest environment also modifies local moisture conditions. Evaporation from the forest floor is relatively low because of reduced insolation and wind velocity. This effect is counterbalanced by the fact that, with the profuse vegetation, high transpiration occurs. The humidity within a forest depends on the density of the forest and the rates of transpiration that occur. It is generally found that the relative humidity in the forest is higher than that of the surrounding non-forested areas, with the highest humidity occurring during the summer.

With local temperature increases of just one or two Celsius degrees, it is projected that seasonally dry and tropical regions will experience decreased crop productivity and associated decreases in soil water resulting in a gradual transition from tropical forest to savanna in eastern Amazonia by the middle of the 21st century [10]. 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. As a result, 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 [11].

3 Geographic Information Systems

Due to deforestation and climate change, it is necessary to inventory, evaluate, and mitigate the damage to forest communities. To do so, researchers require the use of advanced information technology tools that are capable of spatial analysis such as Geographic Information Systems. GIS has a proven track record regarding its usefulness in assessing environmental impacts on woodlands, forests, and other vegetation biomes. However, many challenges remain. For example, urban forests tend to be treated as isolated elements in the development of GIS models 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 limitations, numerous studies indicate that GIS can operate as a cutting edge information technology in the effort to mitigate the myriad environmental impacts associated with climate change.

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 [12].

In addition to its capacity to store massive amounts of spatial data, the main benefit 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.

Examples of GIS applications in forestry management are abundant. In the United States, a GIS was developed for a region in northern Wisconsin which incorporated satellite imagery in order to examine detailed spatial environmental data allowing an assessment of change over time within the forest landscape [13]. A GIS analysis of vegetation structure with forest functions and value in Chicago, Illinois, revealed that local urban forests sequester approximately 315,800 metric tons of carbon annually while removing 5575 metric tons of air pollutants [14]. In Chattanooga, Tennessee, an urban GIS was developed to map the specific location of individual trees and allow users to 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 [15].

Researchers in Germany utilized a GIS to examine the spatial pattern and environmental functions of the urban forest linking environmental planning and urban forestry with general land-use [16]. 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 [17]. Another European 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 [18].

Back in the United States, tree data were obtained from more than 100,000 plots from the U.S. Forest Service's Forest Inventory and Analysis (FIA) Program for eastern North America. The data represented some three million trees and were used to develop a GIS atlas of tress species to assess the probable reaction to several scenarios of climate change. The atlas examines 134 species at 20 kilometer 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 link components of the land, ocean, atmosphere, and cryosphere to represent historical climate variability and estimate projected long-term increases in global temperatures due to human-induced emissions. The GIS reveals that under the worst-case scenario, the density of sugar maples is greatly reduced although its range slightly increases [19].

4 Forest Regeneration

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. 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 and matter that takes place between the biosphere and the atmosphere.

Equipped with the information technology afforded by GIS, organized environmentalists have taken on the task of forest regeneration acknowledging that allowing old growth forest remnants to persist is an important component in the conservation of biodiversity as well as the ecosystem services that were previously provided. The effects on woody generation of established trees during secondary succession in tropical dry forests have been investigated [20]. Along fencerows, barns and other structures, these established trees function as regeneration nuclei. Agricultural fields need to retain forest cover in their vicinity to act as biological corridors and to accommodate the pathways of pollinators, seed dispersers, herbivores, and other organisms serving crucial roles in forest regeneration [21]. Also to be considered are the effects of competition and interference imposed by exotic or non-native species of plants [22].

In an effort to determine the effects of agricultural land uses on subsequent forest regeneration, two major factors should be considered. These are the general conditions of the environment following the abandonment of the field and the presence of propagules. The areal extent, severity, and length of time of the agricultural disturbance also are important considerations for the success of regeneration. The prevalence of each of these factors will influence the availability of propagules as well as the degree of land degradation. As extent, severity, and duration increase, the regeneration potential decreases.

Using studies from Southern Mexico, Martínez-Ramos et al. determined the dominant pioneer species in recently abandoned fields by using demographic analyses [23]. Hardships, or bottlenecks, that trees encounter as they transition from seed to seedling and through subsequent life stages were identified. Additionally, the study addressed successful regeneration at both the field and landscape scales. Information from the farmers who worked the land previously proved more valuable in determining success than were measurements of microclimate and soil conditions. This research provides informative indicators for the selection of specific endemic tree species as well as a broad conceptual framework for successful second growth forest regeneration.

Chazdon and Uriarte addressed a composition of wherein biodiversity conservation and agricultural productivity are reconciled in a patchwork of agro-ecological systems and agroforestry as they are implanted within a matrix of old growth and second growth forests [24]. The identification of land uses that promote successful forest regeneration, and the determination of ecological tools that will serve to restore degraded lands are critical for constructing positive scenarios of agricultural production, biodiversity conservation, and, eventually, the enhancement of rural livelihoods in human-modified landscapes [25].

5 Local Livelihoods

Tree plantations can have rapid growth rates and yield substantial benefits including an economic return for local people. Streed et al. report that small-scale reforestation in Costa Rica with mixtures of native species have proven to be financially profitable both for investors and farmers [26]. Bangladesh has a huge potential for reforestation, and according to Shin et al. replanted forests there could store an average of 92 tons of carbon per hectare [27].

Adams et al. focus on the impacts on the socioeconomic status of local livelihoods from large-scale forest restoration, or forest landscape restoration. The authors differentiate between what is known and what requires investigation. The products gleaned from forests, wood, non-timber resources, and ecosystem services benefit society as a whole and are particularly significant to rural livelihoods. Forest landscape restoration provides a means of mitigating deforestation while combining ecosystem goods and services with development goals. However, there is only scant evidence of the effects on local livelihoods from large-scale restoration. Most of the literature features case studies and almost half of those were conducted in China [28].

For example, Jim and Liu 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 [29]. Zhang and Song report China's forest cover doubled from nine percent in 1949 to 18 percent in 2003 [30]. Fang et al. 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 [31]. In short, forest restoration appears to be a means of improving ecosystem functioning, ecological and economic resilience, and human livelihoods [32].

6 Knowledge Gaps

The topics addressed most frequently in the literature are income, diversity of livelihoods, employment opportunities apart from the farm, reducing poverty, economic equity, and the supply of timber, energy, and ecosystem services. Most research addresses the high degree of influence of government policies. In this invaluable review of the literature, the socioeconomic benefits on local communities from reforestation and restoration programs were mixed. Determining factors include household characteristics, land productivity, land tenure schemes, availability of off-farm employment, and markets for forest products and ecosystem services. The authors conclude that the close monitoring over time of programs already in place along with the determination of clear indicators for success are needed.

Other key gaps in the existing research were enumerated by Uriarte and Chazdon [33]. At the international policy level, there has been an increasing awareness for the need to implement large-scale forest landscape restoration in light of the extensive loss of tropical forest. However, tree plantations have prevailed at the cost of natural regeneration which provides a cost-effective means of achieving large-scale forest landscape restoration. The questions that emerge when determining the use of natural regeneration follow. What tools would prove most useful for identifying and mapping target areas for regeneration? What legal and governmental frameworks will best inspire natural regeneration and how do those change among nations? And what financial systems might encourage natural forest regeneration? What are to become the likely tradeoffs among livelihoods, economic and ecological outcomes of land use changes and how do they change with market forces and climate change? The authors admonish that natural regeneration might not address all tensions and conflicts concerning land use, but under the correct circumstances, it could be a cost effective alternative to tree plantations.

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. 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 [34]. 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.

7 Conclusion

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 in terms of their biodiversity, symbiotic relationships with organisms outside the ecosystem, as well as in terms of their ecosystem services. Neither can reforestation be viewed as a quick fix by the logging industry and nations with large timber 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 [35]. As Lu et al. note, incentive approaches for citizens in the developing world are indispensable for effective conservation and successful management in protected areas [36].

Climate change and deforestation 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 and through deforestation. Deforestation contributes to the increasing amount of carbon dioxide in the atmosphere and is influencing climatic change at the local, regional, and global scales. 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 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 multiple benefits the forests provide.

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