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# Utilizing GIS and remote sensing to inform spatial conservation planning: Assessing vulnerability to future tropical forest loss in southern Belize

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**Abstract:** Throughout the world, deforestation, degradation, and fragmentation threaten the integrity of tropical forests and the biodiversity that they contain. Although southern Belize is generally recognized as a highly forested landscape, it is becoming increasingly threatened as unsustainable agricultural practices reduce its capacity to provide life-supporting ecosystem services. Deforestation data is necessary for forest managers to efficiently allocate resources and make decisions for proper conservation and resource management. This study utilized satellite imagery to map and analyze current forest cover and recent forest loss in southern Belize in order to identify the areas that are the most susceptible to future deforestation. A forest cover change analysis was conducted using a supervised classification of Landsat imagery and ground-truthed land cover points in Google Earth Engine. Then, a proximity-based model was used to predict where deforestation could occur in the future based on the drivers of deforestation. The assessment indicates that the agricultural frontier will continue to expand into recently untouched forests. The results of this study will be used in spatial conservation planning in order to strategically focus conservation efforts in the most threatened areas in southern Belize. The sites that were found to be most vulnerable to future deforestation will be locations for implementing law enforcement and compliance, sustainable agriculture, and community outreach. This method could be applied to conservation planning in other regions to prioritize the protection of threatened areas.

**Keywords:** remote sensing; GIS; deforestation; forest vulnerability; spatial conservation planning; forest cover change; land-use; land-cover; tropical forest; Belize

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## 1. Introduction

The integrity of tropical forests and the biodiversity that they contain are threatened throughout the world by deforestation, degradation, and fragmentation. About half of the world's tropical forests have been cleared [1] and between 1980 and 2000, over 80% of new agricultural land originated from forests [2]. This deforestation has unknown long-term effects on species, ecosystem processes and functions, climate patterns, and the existence of important resources such as medicines and crop relatives [3]. Considering tropical forests' critical function in conserving biodiversity and ecosystem services as well as sustaining local livelihoods, understanding the patterns of forest cover loss and implementing conservation actions in strategic locations to prevent deforestation is crucial.

Reducing the rate of deforestation in any region should involve a multitude of stakeholders and a broad range of conservation actions. However protected area and sustainable livelihood managers have limited resources and therefore detailed information is necessary to prioritize areas to focus law enforcement and compliance, sustainable management, and community outreach. Thus, a need exists to identify the areas most vulnerable to future deforestation in order to strategically implement conservation efforts where they will be the most effective.

Predictive deforestation data can assist forest management organizations in spatial conservation planning to efficiently allocate resources and produce the greatest conservation impact. A multitude of research has focused on the locations and rates of forest cover change based on remote sensing technology. Recently, the results of these analyses have been used to identify the predictors of change and to assess specific areas where forest loss is likely to occur in the future [4-6]. These findings can be used in spatial conservation planning to strategically focus conservation actions in the most threatened areas. We applied this approach to a region in southern Belize.

Belize is generally recognized as a highly forested country with a total forest cover of 62.7% [7]. The Maya Golden Landscape (MGL), located in southern Belize's Toledo District, is still mostly forested and has retained a greater amount of forest cover than other areas in Belize. The 770,000-acre MGL is a mosaic of private and governmental protected areas, private lands, and predominantly Maya communities. The area forms the primary biological corridor in southern Belize, which is the only remaining broadleaf forest link between the Maya Mountains and the marine ecosystems of southern Belize. This connection is critically important on both a national and regional scale as part of the Mesoamerican biological corridor.

The MGL is becoming increasingly threatened as unsustainable land use practices reduce the land's capacity to provide life-supporting ecosystem services. The region is farmed predominantly through slash-and-burn agriculture. Traditionally, farmers will cultivate a plot until it decreases in productivity, at which point it will be left to re-grow natural vegetation for about ten to fifteen years. During this fallow period, the soil is able to regain fertility for a following cultivation. However, in the last few decades the fallow period of most plots has been reduced to two to three years due to an increase in population and a shortage of land. Therefore, the soil is usually not able to completely regain its fertility, resulting in more numerous and shorter agricultural cycles and increased deforestation. While farmers continue to clear secondary-growth forests that were left in fallow, they have also begun to cultivate forests that have not been cleared in the recent past. There has also been an increase in other unsustainable agricultural practices in the MGL such as large mechanized farms.

This research was conducted in order to assist in conservation planning and management of the MGL in an effort to abate future deforestation. It investigates the anthropogenic conversion of forest using remote sensing, deforestation driver variables, and a GIS proximity-based model to determine the areas most susceptible to future deforestation in the region.

## 2. Experiments

### *2.1. Remote sensing methodolgy*

A forest cover change analysis was conducted utilizing a supervised classification of Landsat imagery in Google Earth Engine from 2014 to 2016. Training data used for this study was collected from field survey, satellite imagery, aerial photography, ecosystem layers [8], and fire point data [9]. The field survey involved the collection of GPS points of land cover types. Forests, regenerating fallow areas, anthropogenic areas, and non-forest natural areas were classified within the MGL boundary in 2014 and 2016. Regions classified as non-forest natural areas such as savannas (including transitional zones), large wetlands (including mangroves), large bodies of water, and marine ecosystems were excluded from the analysis since the focus of the study was on the conversion of tropical forest to anthropogenic areas. These non-forest natural areas were determined based upon the [8] data as a guide, with a few minor modifications based on data collected from the field survey on transitional natural communities. The land cover results were checked against both images and errors were corrected through additional field surveys and imagery training data.

The extremely dynamic and highly successional nature of the patches that are continually subjected to slash-and-burn agriculture present a unique challenge to determining forest cover change in the MGL. Within this patchy landscape, regenerating secondary-growth forest only lie in fallow for several years before they are subsequently “deforested” and converted to agriculture once again. Therefore, calculating such highly dynamic rates of deforestation and natural regeneration is generally irrelevant based on the overall balance throughout the landscape, as determined by earlier deforestation analyses [7, 10]. In this analysis, the areas that have been continually subjected to slash-and-burn agriculture since 1980 have been categorized as regenerating forest and have been excluded from the calculation of deforestation within the MGL. Therefore, the deforestation calculated for this analysis only represents deforestation that has occurred in forest that has not been cleared since 1980. Belize does not necessarily contain “primary” or “old-growth” forest due to its past history of land use and natural disasters, such as hurricanes. Therefore, areas that have not been cleared by humans since 1980 are referred to in this paper as “older-growth forests.”

### *2.2. Future deforestation vulnerability model methodology*

To assess vulnerability to future deforestation and predict the forest patches that may be cleared within the next ten years, a tool called the Land Change Modeler (LCM) [11] was implemented. LCM analyzes previous land cover change, models the potential for deforestation, and predicts the forest patches that may be deforested in the future. We conducted an additional forest cover change analysis in LCM between 2014 and 2016 to identify focal areas of change. Next, transition potential maps were created to represent the likelihood for a patch of forest to be converted to an anthropogenic area [12]. These were generated using data from the deforestation analysis and spatial variables that had been identified as the drivers of deforestation in the MGL. We implemented the model with a multi-layer perceptron neural network as studies have found that it outperforms other methods [12]. The result includes a map of the vulnerability of the landscape to forest conversion, which determines all of the areas that contain suitable conditions to experience deforestation, as well as a prediction map of land cover at any designated point in the future. We produced a map which envisions the potential landscape for 2026. All calculations preformed from the results of the analysis and model were processed in ArcGIS 10.5 [13].

We selected the spatial drivers of deforestation that affect forest accessibility and agricultural attraction such as proximity to roads, proximity to settlements, proximity to forest edges, and level of protection. The variables were determined based upon previous studies that identified the major drivers of deforestation in tropical Latin America [14, 15] and the visual inspection of land cover change analyses of the MGL since 1980. All proximity based data was calculated utilizing Euclidean distance models in the LCM. Level of protection variables were classified loosely based upon IUCN’s protected area categories. For example, the following are designated levels of protection from least likely to most likely to be deforested: (1) strict nature reserves, (2) national parks and wildlife sanctuaries, (3) forest reserves, and (4) areas with no protection. All factors that were included in the model had a strong Cramer’s V predictive power ($V \geq 0.3$) and significant p-value ($p < 0.001$). Biophysical characteristics such as slope, elevation, and soil type were tested in the LCM as potential deforestation drivers but were determined to not to be strong predictors to change. Spatial variable data was produced by [8] or through this forest cover change study.

## 3. Results

### *3.1. Forest cover change analysis results*

The results of this analysis show that the MGL has remained a highly forested landscape yet is threatened by forest conversion. Seventy-five percent of the MGL has remained in older-growth forest, not including regenerating forest, as compared to 62.7% for the whole country [7]. Since 2014, 5,165 acres have been cleared, resulting in a deforestation rate of 0.89% for older-growth forests. The rate of older-growth forest loss within protected areas from 2014-2016 in the MGL is only 0.12%, while it is 2.54% outside the boundaries of protected areas. Several protected areas in the MGL, such as Bladen Nature Reserve (BNR), Golden Stream Corridor Preserve (GSCP), and Payne's Creek National Park (PCNP) did not exhibit deforestation from 2014 to 2016 while others, such as Columbia River Forest Reserve (CRFR), Maya Mountain North Forest Reserve (MMNFR), and Deep River Forest Reserve (DRFR) did, usually at the edges of their borders.

### *3.2. Future deforestation results*

The maps depicting vulnerability to future deforestation of all forest types, the hotspots of vulnerability to future deforestation of only older-growth forests, and forest cover predictions for 2026 are presented in Figure 1. The assessment indicates that the agricultural frontier will continue to expand into older-growth forests. According to the prediction model, the older-growth forests will decrease from 75.5% in 2016 to 71.2% in 2026. The predicted deforestation is based on several assumptions including (1) that the forest will change in the same manner as the 2014-2016 analysis and (2) that the drivers will not vary significantly within the next ten years.

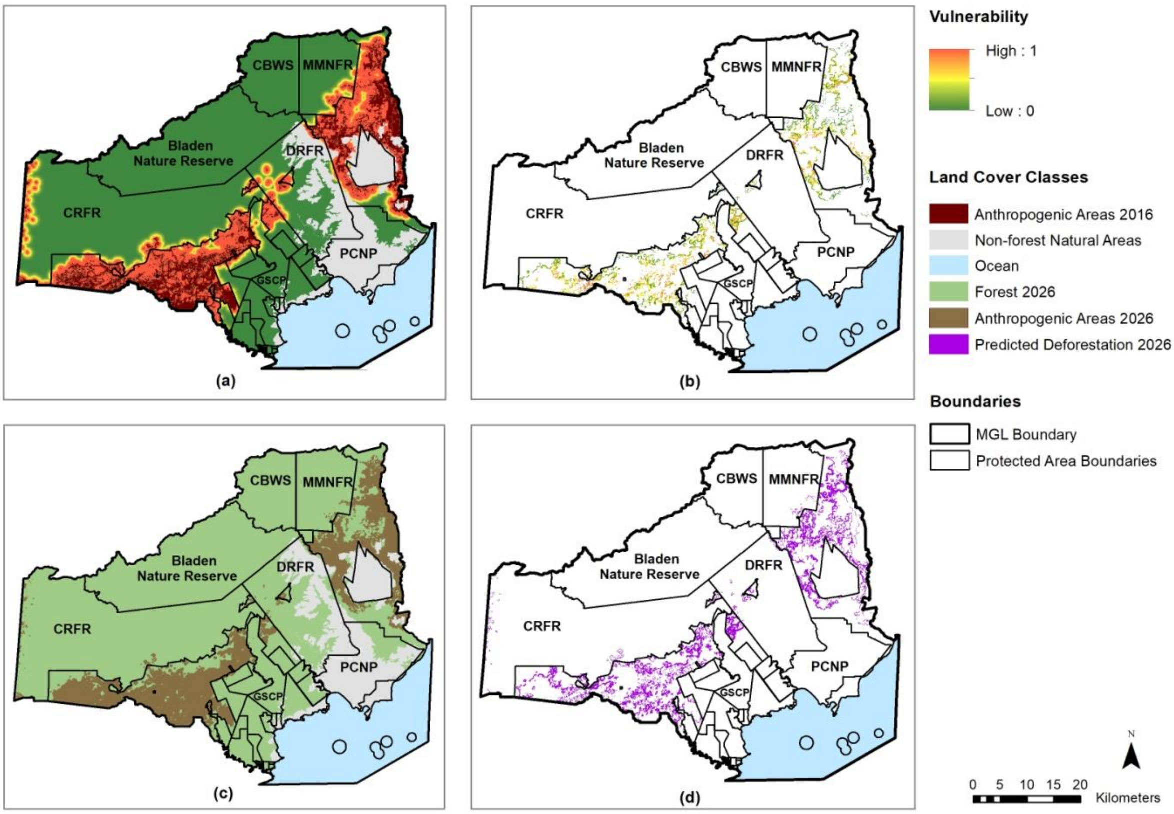


**Figure 1.** Modeled forest cover maps. (**a**) Vulnerability to future deforestation of older-growth and regenerating forests, higher values represent higher vulnerability; (**b**) hotspots of vulnerability (top 10% of pixels) for future deforestation of older-growth forests; (**c**) Forest cover predicted for the year 2026; (**d**) Predicted deforestation of older-growth forest for the years 2016-2026. Maps created in ArcGIS 10.5 [10].

## 4. Discussion

Although the MGL is still mostly forested, the agricultural frontier has advanced into older-growth forests, due to unsustainable small-scale and large-scale agriculture. Shorter crop cycles have led to a decrease in soil fertility and an expansion of agriculture land in search of more fertile soils. The model predicts that this will continue to occur in the future. The sites that are the most susceptible to future forest loss are located outside of reserves (Figure 1b). Only a few forested regions outside of protected areas are predicted to remain after 2026, according to the model (Figure 1c), resulting in increased pressure on reserves.

Deforestation has been observed within CRFR, MMNFR, and DRFR and the model predicts that these protected areas are vulnerable to future conversion. The projected increase in deforestation along the boundaries of these reserves can be related to their close proximity to drivers of deforestation. The places in which persons are clearing protected areas are typically a result of lack of arable, accessible land outside of protected areas.

While deforestation occurred in MMNFR from 2014-2016 and the model predicts that these clearings will increase slightly, the model does not consider that an agroforestry concession was implemented in 2015 in order to attempt to prevent future deforestation. Therefore, most likely the area is much less vulnerable to deforestation than predicted.

Deforestation in CRFR has been concentrated on the southern and western edges. On the western boundary of CRFR, which lies adjacent to the Guatemala border, small clearings have advanced into the reserve and the model predicts that this will most likely progress in the future. The Guatemalan side of the border near CRFR has been heavily deforested. Guatemalan citizens began crossing the border into Belize in the early 1990s to exploit the relatively untouched land for illegal resource use such as farming, logging, and hunting. The remoteness of the border, lack of personnel, lack of finances, and high danger of armed Guatemalans are barriers to enforcement [16]. An old logging road leading into CRFR has provided access to an agricultural area that has expanded over time, which will continue in the future according to the model. In addition to the expansion of current cleared areas, the model also predicted new incursions within the reserves along their boarders, especially the southern boundary of CRFR. Without proper conservation planning and strategic placement of patrols on the southern boundary, these forests could be lost.

The vulnerability and prediction maps can help protected area and sustainable livelihood managers identify and prioritize where conservation actions should be strategically focused. These results will be disseminated to stakeholders within the MGL in hopes that they may be incorporated into their conservation planning process. The locations that were found to be most vulnerable to forest conversion can be sites for implementing sustainable agriculture, community outreach, and increased protection. Law enforcement and compliance actions, such as increased patrols, can be implemented within the most vulnerable regions of protected areas. Additionally, community outreach and sustainable agricultural practices can be implemented in the communities that are the most vulnerable to deforestation in order to prevent future forest conversion. Proper fire management learned by farmers in fire trainings can help to reduce the risk of escaped fires in threatened areas. By shifting from slash-and-burn agriculture to agroforestry or inga alley cropping, farmers can increase the soil fertility on their land and reduce an increasing tendency to cut older-growth forest due to their search for additional land.

## 5. Conclusions

This study incorporates the results of a forest cover change analysis with the most significant predictors of forest conversion in a GIS-based model to determine the areas most vulnerable to future deforestation in the region. The model predicts that the Maya Golden Landscape will continue to exhibit an expansion of agriculture into older-growth forest. The vulnerability and prediction maps can be used to strategically focus conservation efforts by stakeholders to effectively allocate resources. Communities rely on forests for farmland and for the ecosystem services that they provide. All stakeholders must build capacities and knowledge in order to avoid reaching a point in which the forest has been depleted. Through sustainable land use, based on long-term planning approaches, future generations of MGL inhabitants will be able to live off the land, sustainably gather resources, and conserve one of the most important forests in Mesoamerica.

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**Author Contributions:** Carly Voight conceived, designed, and performed the experiments and analyzed the data; Carly Voight, Said Gutierrez, and Karla Hernandez-Aguilar selected the deforestation driver variables; all authors wrote the paper.

**Conflicts of Interest:** The authors declare no conflict of interest.

## Abbreviations

The following abbreviations are used in this manuscript:

CRFR: Columbia River Forest Reserve
DRFR: Deep River Forest Reserve
LCM: Land Change Modeler
MGL: Maya Golden Landscape
MMNFR: Maya Mountain North Forest Reserve

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