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Forestation in Puerto Rico, 1970s to Present

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Abstract

It is important to monitor the trend of forestland changes, as forests are vital sources and sinks of carbon on the earth. One of the most densely populated jurisdictions of the United States, Puerto Rico, has experienced significant transformations in the past century. This study examines forestation in the main island of Puerto Rico during the past four decades using feature extraction and change detection analysis in multitemporal Landsat satellite imagery. The results of the study show that forest cover in Puerto Rico had almost tripled from 15.7% to 45.7% between 1972 and 2014. Moreover, the forestation trend and pace in abandoned coffee plantations and pastures continued after 1990, driven by continuous socioeconomic transformation. Natural forestation and conservation efforts from the government and nongovernment organizations have also contributed to the forest growth on the island. The information gained and lessons learned during the process may be applied to other densely populated tropical insular territories.

Keywords: forestation, landscape change, Puerto Rico, satellite remote sensing

1. Introduction

Forests are vital sources and sinks of carbon on the earth. About one-third of the earth's land surface is covered by forests, which store almost half of the world's terrestrial carbon in wood, leaves, roots, and soil. In developing countries, forests contribute largely to livelihood security, provide major energy sources, and various ecological, economic, social, and aesthetic functions for people (FAO, 2014; Miura et al., 2015; Romijn et al., 2015). According to Ruhyan and D'Odorico (2016), more than 27% of the global land was converted from forest to agriculture through the 1900s. The major drivers of deforestation were agriculture, logging, and biofuel production. Increases in deforestation have threatened many ecosystems (Chazdon, 2008). However, it was found that, between 1990 and 2015, the total growing forest stock volume has increased in East Asia, Caribbean, Western and Central Asia, North America, Europe, and Oceania, with the highest relative increase in East Asia and the Caribbean, whereas the opposite was true for the rest of the subregions of the world (Köhl et al., 2015).

Forestation is defined as the planting of trees or the natural establishment of forest growth over a wide area, wherever it had or lacked forest. It includes two categories: reforestation and afforestation. It was found that the forest cover in Puerto Rico increased from 9% to 37% between 1950 and 1990, mainly due to agricultural fields being converted into forests (Rudel et al., 2000). The alternative economic opportunity such as manufacturing work and the dropping prices of the coffee market led farmers to abandon their farms or coffee plantations (Rudel et al., 2000). West and Boswell noted in 1989, "Few countries on Earth have experienced transformations in the last four decades that are as great as those that have taken place in Puerto Rico".

It is important to know the trend of forestation in Puerto Rico because the island's forests provide the habitat for thousands of species of flora and fauna, supply vital life support in the matter of water supply, agriculture, industry, and tourism (Miller and Lugo, 2009). Nevertheless, further detailed research for Puerto Rico on forestland change is limited after the study by Rudel et al. (2000). Zimmerman et al. (2000) studied barriers to forest regeneration in an abandoned pasture in Puerto Rico. They noted that dispersal issues, competition with herbaceous vegetation, predation, and poor soil conditions were the major barriers to forest regeneration. Chinea (2002) documented forest structural and compositional changes along gradients of elevation and time since abandonment in the Humacao Municipality of eastern Puerto Rico. However, more research on forestation in this study site, especially for the most recent three decades, is necessary.

In this context, this study aims to investigate whether or not forestation occurred continuously in recent decades, especially after 1990. We assume that the trend has continued due to the consistent economic changes and the decreasing population of the island. Multitemporal Landsat satellite images were used to extract forests in Puerto Rico for every decade since the 1970s using an object-based feature analysis. The spatial patterns of forest cover changes in the most recent three decades were mapped using a change detection method. In addition, to understand the drivers and dynamics of the forestation process, historical landscape changes were also discussed.

2. Study Site

2.1 Geography of Puerto Rico

Located between the Caribbean Sea and the North Atlantic Ocean, Puerto Rico is an archipelago that consists of the main island of Puerto Rico and several smaller ones such as Mona, Vieques, and Culebra (Figure 1). Only three islands have permanent populations: the main island, with 99.7% of the population, and Vieques and Culebra with 0.3% of the population (Castro-Prieto et al., 2017). This study site is focused on the main island, the easternmost island of the Greater Antilles and the third largest island (about 8,870 km^2) in the United States (U.S.). It is rectangle-shaped, approximately 180 km from east to west and 65 km from north to south. Mountainous areas (60%) dominate Puerto Rico's physical landscape. With the highest peak of 1,338 m, the "La Cordillera Central" (The Central Range) is the major mountain range, extending through the entire island from east to west. The northern region is characterized by karst topography while some low-lying coastal plains are located adjacent to the seas surrounding the island. Puerto Rico has a climate that is tropical and predominantly maritime, with temperatures exhibiting small seasonal differences, and vegetation zones ranging from dry, semi-deciduous forests in patches and bands on the north and east coasts and in the southwest part of the island, to moist forests that cover a considerable area of the island, to wet and rain forests at higher altitudes (Daly et al., 2003). The average temperature is 28 °C throughout the year. According to Van Beusekom (2014), the rainy season is bimodal, with an earlier period of precipitations from May through June and a later period from August to November.

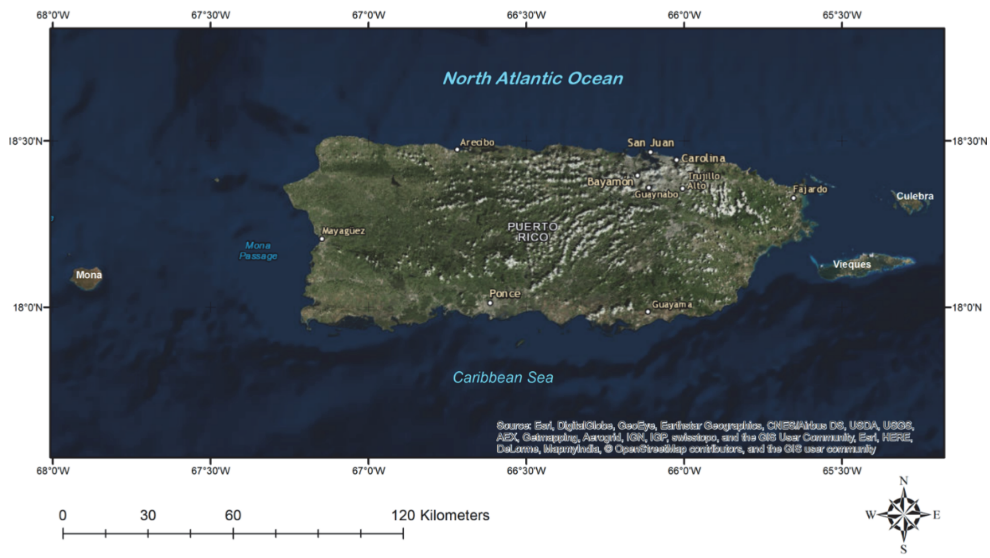


Figure 1. Puerto Rico

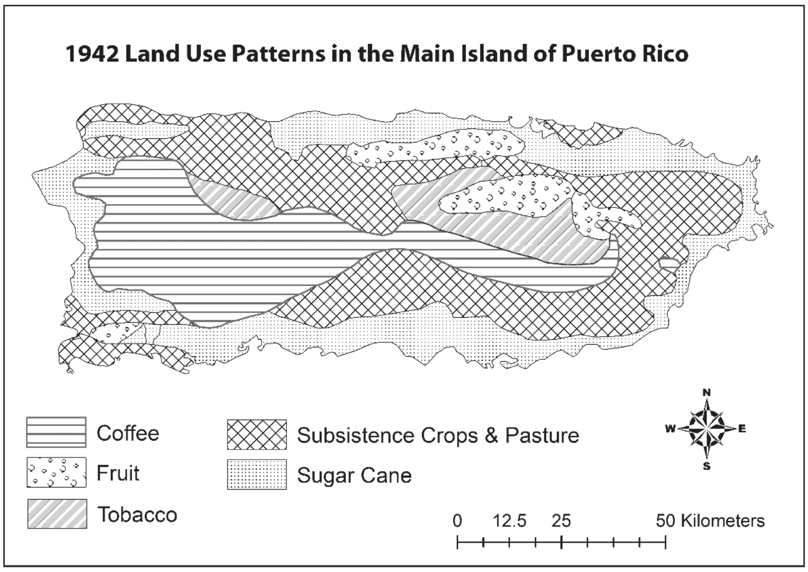
Puerto Rico has a total population of about 3.5 million and is among the most densely populated U.S. jurisdictions in the tropics. Nevertheless, the population of the territory declined by ~83,000 people, or 2.4%, from the year 2000 to 2010, and this population decrease was attributed to an economic crisis beginning in the mid-2000s (Castro-Prieto et al., 2017). These islands were a colony of Spain from 1493 until the Spanish-American War in 1898, when the territory became the unincorporated part of the U.S. During the second half of the past century, Puerto Rico's economy rapidly shifted from an agricultural-based economy to an industrialized economy centered on manufacturing and services (Gonzalez-Mejia and Ma, 2017).

2.2 Historical Landscape Changes of Puerto Rico

Between the 16th and 20th centuries, vast areas of Puerto Rico's northern coastal alluvial flats were deforested and used chiefly for sugar cane plantations, with some of these lands subsequently converted to grazing (Abelleira-Marinez et al., 2015). By 1899 pastureland covered 55% of the island, and more than 90% of its territory was in some form of agriculture by the turn of the 20th century, with remnant forest limited to small areas (Grau et al., 2003; Pascarella et al., 2000). During the first four decades of the 20th century, land use patterns remained almost the same (Figure 2a; James, 1942). More than half of the total number of farms in the main island of Puerto Rico had one of the three crops – sugar cane, coffee, or tobacco, as the main source of income (Pico, 1939). By 1942, sugar cane plantations made up more than ¼ of the total land and were located close to the coast but extended to inland terraces while coffee plantations comprised about 23% and were concentrated in the interior highlands in the central and west parts of the island (Figure 2a). In addition, subsistence crops and pasture together comprised more than one-third of the total land. According to Pico (1939), large farms (> 500 acres or 202 ha) dominated most of Puerto Rico at that time. However, small farms were numerous and more than 50% of the farms were less than 4 ha (10 acres) in size although they only made up 10% of cropland (Pico, 1939).

In the last six decades of the 20th century, the island's natural and cultural landscapes have experienced significant changes. According to Aide et al. (1995), economic transformations occuring after World War II have noticeably decreased the pressure of human activities on the main island's forests. Until the 1950's, some areas in northern Puerto Rico were used for agriculture and cattle grazing, but after the abandonment of these activities, forest regeneration has occurred naturally (Fonseca-Da Silva, 2014). By 1974, the total areas used for sugar cane and coffee plantations in the main island were both declined to approximately 16-18% whereas forest and urban increased to 10% and 5%, respectively (Figure 2b; Pico, 1974). Pastureland made up more than 30% of the total land, attributed to the newly developed aviculture and dairy related activities in the island. The land use patterns were more widely dispersed by 1974 as compared to 30 years ago (Figure 2b). In addition to increases in the area of secondary forests, some urban lands and construction sites have expanded too (Wu and Heberling, 2016). Furthermore, during the last two decades, some government and nongovernmental organizations in this part of the Caribbean have been involved in initiatives aimed to create nature reserves and stimulate "nature conservation projects in an attempt to ensure the preservation of biodiversity" (Rivera-Collazo 2015, 1605).

(a)



(b)

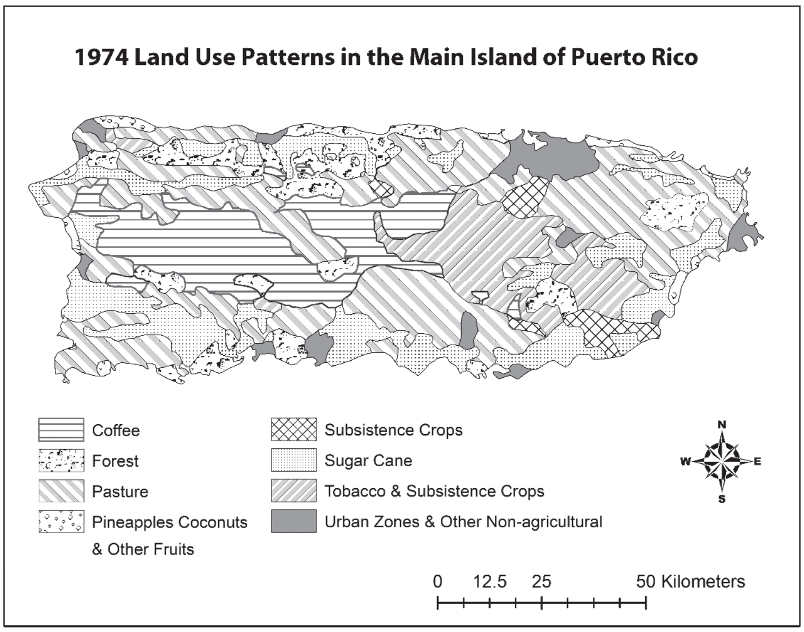


Figure 2. (a) Land use patterns in the main island of Puerto Rico in 1942 (modified from James, 1942); (b) land use patterns in 1974 (modified from Pico, 1974)

3. Methods

3.1 Mutitemporal Landsat Satellite Images and Preprocessing

In this study, multitemporal Landsat images were downloaded from the United States Geological Survey (USGS) Earth Explorer website (https://earthexplorer.usgs.gov/). Landsat satellites provide us 45 years of imagery with moderate-resolution and synoptic view, which is important for the purpose of this study. The main island of Puerto Rico is contained within Landsat Paths 4-5 and Rows 47-48 four different tiles in the Worldwide Reference System (WRS). Therefore, four scenes were selected for each of the five representative years from the past four decades: 1972, 1985, 1992, 2003, and 2014. These images were chosen based on their relatively highest qualities and least acquisition differences among the four scenes within the same year. Table 1 summarizes the detailed information of the acquired Landsat data.

Once the data was download, it was then extracted and inspected to make sure the quality was adequate for the analysis. In addition, the images from 1972 were collected by the Multispectral Scanner (MSS) sensor, which has a lower spatial resolution and less spectral bands than those of the Thematic Mapper (TM) and Operational Land Imager (OLI) sensors (Table 1), but they are the best available ones from the 1970s. For the image chosen for the 1980s, it was decided to combine the images from 1985 with the ones from 1988 to minimize the amount of cloud cover.

Table 1. Detailed information of the acquired Landsat data.

Year	Acquisition date of the two western images (Path 5, Rows 47-48)	Acquisition date of the two eastern images (Path 4, Rows 47-48)	Sensor	Spatial resolution	Spectral resolution
1972	1972-10-18	1972-10-17	MSS	80 m	Green, Red, Near Infrared 1, Near Infrared 2
1985	1988-03-10	1985-01-21	TM	30 m (Multispectral) 120 m (Thermal)	Blue, Green, Red, Near Infrared, Middle Infrared 1, Thermal Infrared, Middle Infrared 2
1992	1992-08-19	1992-06-25			
2003	2003-01-22	2003-03-20			
2014	2014-11-28	2014-11-21	OLI	30 m	Coastal Aerosol, Blue, Green, Red, Near Infrared, Middle Infrared 1, Middle Infrared 2, Cirrus

The originally downloaded imagery was delivered in TIF file for each of the bands. These individual bands were stacked together in ERDAS/IMAGINE. Because some of the bands, such as the thermal infrared band from the TM sensor and the coastal aerosol and cirrus bands from the OLI are not very useful for the purpose of this study, they were excluded from the datasets and stacking process. Almost all of the downloaded images were already accurately rectified by the USGS. However, the two western images (WRS Path 5; Rows 47 & 48) of 1972 had to be rectified again manually to align with the two eastern ones (WRS Path 4; Rows 47 & 48).

In addition, all the images have already been projected in UTM WGS 84 coordinate system. However, they were in two different UTM Zones: 19 N and 20 N. Therefore, all eastern images (WRS Path 4) were reprojected from Zone 20 to Zone 19 as the western images (WRS Path 5) cover the majority of the study site. In order to create a single seamless image, the four images of each year were mosaicked using the color balance feature and the northwestern tile as the reference scene. The final mosaicked Landsat images from 1972 to 2014 were then clipped using a rectangle Area of Interest (AOI) layer drawn around the island.

3.2 Forestland Mapping

To extract the forested areas from the Landsat imagery, we used Feature Analyst, an object-based image classification software that provides a suite of machine learning algorithms for land use and land cover (LULC) feature extraction. Feature Analyst has been widely used to map LULC features (Nagel, et al., 2014; Yuan et al., 2015; Chubey et al. 2006, Stueve et al. 2015). As an extension in ArcGIS, Feature Analyst possesses several advantages over traditional pixel-based classifiers: (1) it uses both spectral and spatial (shape, size, elevation) information; (2) it can include contextual (neighborhood, texture) information; (3) Foveal representation and hierarchical machine learning. More details about the software and its advantages can be found in Opitz and Blundell (2015).

Training polygons were drawn carefully on the screen to represent the typical spectral, shape, pattern, texture, and other information of forest. The historical high-resolution images in Google Earth from 1984 through 2016 for this study site were used as the visual reference to locate accurate training polygons. Once an adequate number of training polygons had been collected, the Supervised Learning Process was run using the “Land Cover Feature” as the feature selector and an input foveal representation of “Manhattan” with a pattern width of five pixels.

Once that forest land cover map was created, it was further refined using the Hierarchical Learning option, which allowed us to add missed features and to remove clusters that were incorrectly classified. This refinement process was performed recursively until the resulting forest layer appeared to be accurate when comparing them with the Landsat imagery and the Google Earth images. To assess how well the forest classifications compared with other inventories, the results were also compared to the Puerto Rico's National Forest Inventories (NFIs) conducted by the U.S. Department of Agriculture (USDA) Forest Service and the global Forest Resources Assessments (FRAs) by the Food and Agriculture Organization (FAO) of the United Nations.

3.3 Forestland Change Analysis

The final classification maps were converted to raster images using the Vector to Raster tool in Feature Analyst. The resulting raster images were used to determine the changes in forested land cover using a customized change detection model created in ERDAS/IMAGINE. This model took two times of forest cover maps to evaluate whether there was a change between the two images, which would represent the growth or diminishing of the forests from time 1 to time 2. We selected the 1985/1988 classification instead of the 1972 classification as the time 1 image for following reasons: (1) the mid-1980s has the same spatial resolution as that of the 2014 (time 2) image, which makes the two times' images more comparable; (2) the mid-1980s classification based on the TM sensor seems to be more accurate than the 1972 classification derived from the MSS sensor due to the higher spectral resolution of TM data and the availability of the Google Earth historical images for the 1980s; (3) our main interest was to investigate if forestation has occurred continuously after the period of 1950-1990 studied by Rudel et al. (2000). To obtain more accurate results, the change detection map from the model was further refined by manually correcting the main misclassified clusters caused by clouds and their shadows.

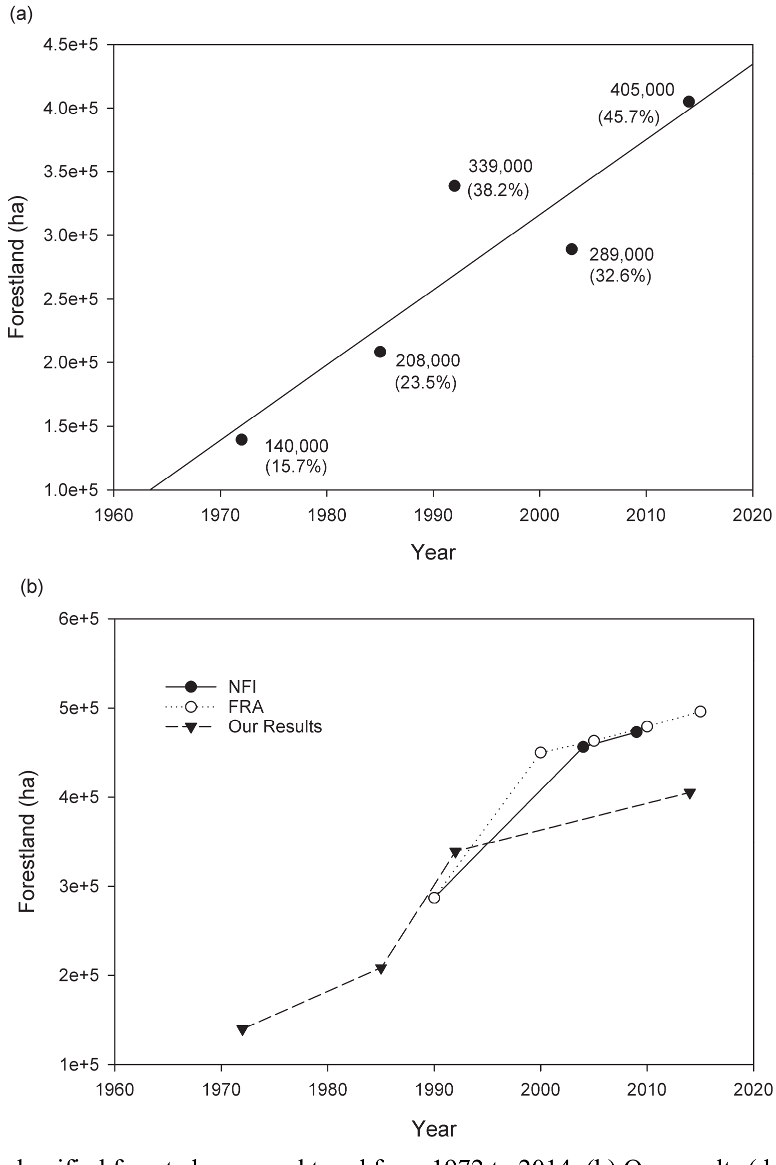


Figure 3. (a) The classified forested areas and trend from 1972 to 2014; (b) Our results (data from 2003 was excluded due to cloud contamination) compared to NFI and FRA

4. Results and Discussion

The classified forested areas from 1972 to 2014 were graphed in Figure 3a, which indicates the total forested area increased significantly 190% from approximately 140 thousand hectares in 1972 to 405 thousand hectares in 2014. However, the reversing trend from 1992 to 2003 shown in Figure 3a might be attributed to some classification errors. Errors could have also occurred due to differences in the images themselves. When evaluating the results and accuracy of the classification maps, clouds and their shadows appeared to be an issue as they were usually classified as nonforested areas. Cloud covered significantly more of the 2003 image than the 1992 image, especially for the northeastern part of the island. There could be forested land under the clouds that is not classified, which would lead to a lower reported forest area in 2003. Moreover, different people performing the same analysis may yield different results; however, this effect was minimized by frequently comparing the images to ensure the methodologies and interpretations lined up.

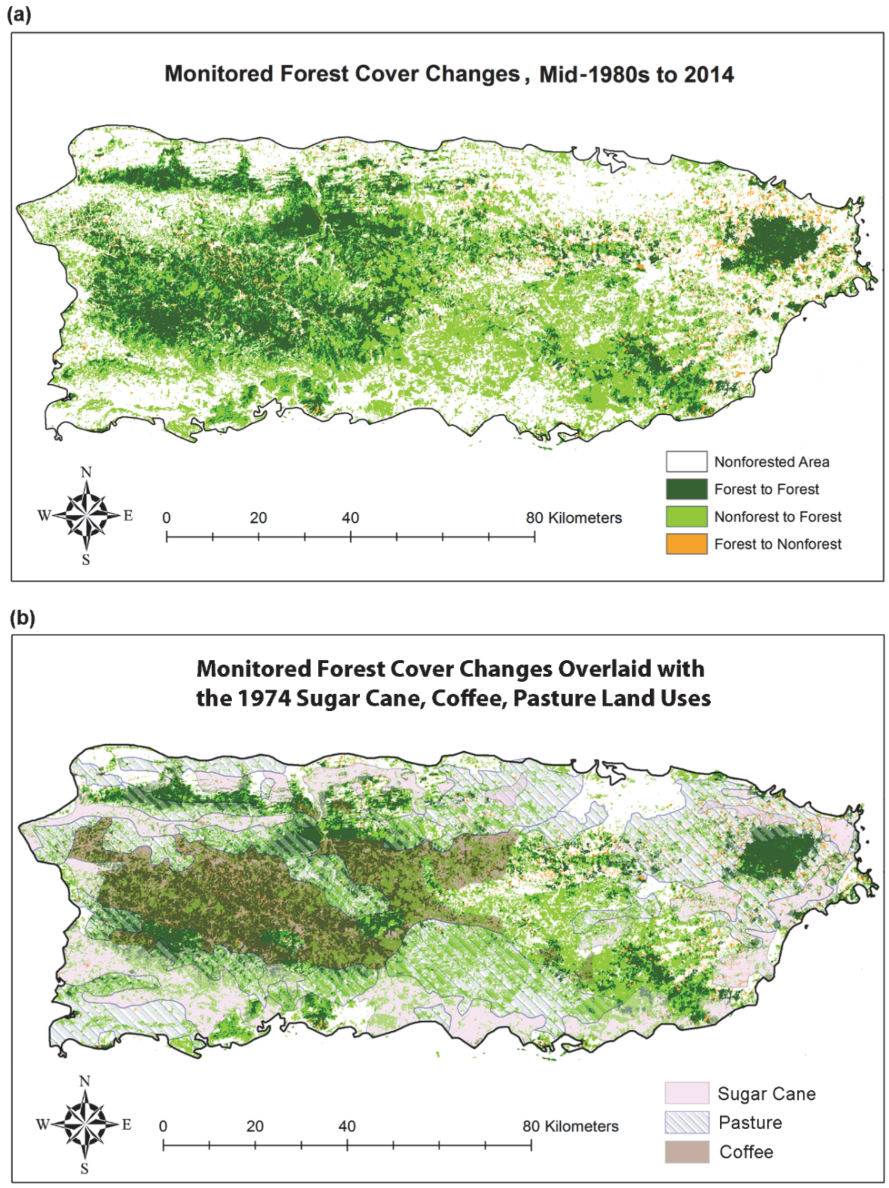


Figure 4. (a) Forestland conversions from the mid-1980s to 2014 (b); Forest cover changes overlaid with the major types of land use from 1974

The increasing trend shown in the data conforms to the other two inventories (NFI and FRA). However, the amount of forestland derived from this study is lower than the NFI and FRA, except for the year of 1992 (Figure 3b). This might be attributed to the fact that the NFI and FRA were derived from different survey methodologies and that their definition of "forest" is different from our satellite-based inventory (Brandeis and Turner 2009; Franco et al., 1997; FAO, 2012). The NFI by the USDA indicated a total 185,791 ha gain of forestland from 1990 to 2009 (Franco et al. 1997; Brandeis & Turner 2009) while the FRA disclosed a very similar number of 192,000 ha from 1990 to 2010 (FAO, 2015). However, both inventories lack spatial information and do not provide the change maps of forests. In addition, the U.S. Forest Service (USFS) produced Puerto Rican National Land Cover Data (NLCD) tree canopy maps for 2001 and 2011, which contain the information of 0-100 percent tree cover for each of the 30 m pixels. However, according to MLRC (2014), the NLCD 2001 and 2011 tree canopy layers are not suitable for directly change analysis because they were created by different mapping methods.

Figure 4a shows the spatial locations and patterns of forestland changes from the mid-1980s through 2014. The major areas of forest growth were located in the central and south-central parts, as well as the peripheries of the original forested areas, where were originally dominated by coffee plantations and pastureland. In particular, some private lands surrounding the Guánica Forest, a 4000-ha tropical dry forest located along the Caribbean coast of southwestern Puerto Rico, are in constant change due to a combination of human and natural disturbances. Furthermore, Guánica forest is primarily semi-deciduous, characterized by a high number of trees that are short in stature and small in diameter like scrubs (Dunphy et al., 2000), with mature forest intermingled with pioneer stands (Van Bloem et al., 2006). Due to the aforementioned two reasons as well as variations in vegetation health and image quality, some of the Guánica Forest and its surrounding areas might not be classified as forest in the mid-1980s' map, therefore these areas are shown as "Nonforest to Forest" change in the figure. On the other hand, south-central Puerto Rico shows a more definite transition from pastureland to forest.The change map also reveals a small amount of forest loss, while some of which is due to cloud contamination, much of which is likely due to the growth of San Juan and other cities. Conversion of forested land to developed land can be found in areas around the cities.

Forestation from 1950 to 1990 was characterized as "spontaneous reforestation" by Rudel et al. (2000) who reported that the reversion of agricultural lands to forest occurred most frequently in coffee-growing regions as prices in coffee markets and productivity trends on coffee lands probably pushed many Puerto Rican small land owners out of agriculture. This is confirmed by Figure 4b, from which we can see many original coffee farms from 1974 were converted to forestland by the mid-1980s, and this conversion trend continued between the mid-1980s and 2014. Agriculture land was abandoned as people moved to urban areas for manufacturing jobs or migrated out of Puerto Rico, or because changes in the coffee market put coffee plantations out of business (Rudel et al., 2000). Figure 4b also revealed that there were large amounts of pastureland, especially in the south-central region, converted to forest since the mid-1980s.

By comparison, the forestation since the 1990s could be a combination of natural reforestation of abandoned agricultural land and conservation efforts. According to Grau et al. (2003), since the 1940s, out-migration was common on the central-western mountains of the island, while urban areas and communities along the northeast coast received most of the internal migrants, consequently experiencing considerable population growth. The central-western mountains were famous for its coffee plantations, and the planting of coffee flowering plants create a series of conditions that facilitate forestation at times when this form of agriculture ends. According to Pascarella et al. (2000: 218), "abandoned coffee plantations have initial starting conditions more similar to forest and might attract seed dispersers for feeding, resting, or nesting activities; we predicted that basal area, species richness, and species composition would recover faster in abandoned coffee plantations than in abandoned pastures." Once these lands are abandoned, they will either recover to forest or become grasslands.

To further analyze the drivers of land use change, we also summarized land in farms by major types from 1969 through 2012 in Table 2 based on available USDA Census of Agriculture (https://www.agcensus.usda.gov). The 2017 agricultural census has yet to be published. The pastureland in the table was aggregated from the "cultivated or improved pasture", "natural pasture", and "other pasture" of the census. Additionally, the woodland class includes: "woodland", "forest", "underbrush", and "woodland pasture". Table 2 reveals that both the total "land in farms" and the major types of farmland decreased dramatically from 1969 to 2012. Most notably, sugar cane farmland decreased by 98.5% between 1969 and 2002 while coffee land reduced by more than 52.3% from 1969 to 2012. Pastureland and Woodland had some fluctuations during the 43-year span; however, they both showed a general declining trend as well.

Table 2. Farmland in total and by major types of farms (ha) and their percent changes from 1969 to 2012, derived from USDA Census of Agriculture.

Year	Land in Farms	% Change of Land in Farms	Sugar Cane	% Sugar Cane Change	Coffee	% Coffee Change	Pasture (excluding woodland pasture)	% Pasture Change	Woodland (including woodland pasture)	% Woodland change
1969	393524	-	144272	-	52718	-	152144	-	58320	-
1974	408817	3.9	96588	-33.1	45300	-14.1	231207	52.0	44661	-23.4
1978	337495	-17.4	65285	-32.4	60973	34.6	183485	-20.6	40637	-9.0
1982	281397	-16.6	35732	-45.3	61606	1.0	146171	-20.3	32800	-19.3
1987	274745	-2.4	26268	-26.5	53501	-13.2	137464	-6.0	38416	17.1
1992	288546	5.0	21255	-19.1	62521	16.9	146747	6.8	25125	-34.6
1998	340133	17.9	9376	-55.9	61181	-2.1	176994	20.6	41188	63.9
2002	271440	-20.2	2128	-77.3	41678	-31.9	113286	-36.0	25531	-38.0
2007	203442	-25.1	-	-	31736	-23.9	106090	-6.4	14288	-44.0
2012	229900	13.0	-	-	25133	-20.8	112666	6.2	16786	17.5

Because the USDA Census of Agriculture doesn't provide statistics of forest land, we estimated the forest land changes from 1969 to 2017 based on the linear trend line (shown in Figure 3a) identified in our study (Table 3). The forestland in this table includes both natural forest and cultivated forest. In addition, the population changes were also interpolated based on the U.S. decennial census population data since 1970 (https://www.census.gov). The results are summarized in Table 3, using a year list that matches the one in Table 2. It is evident that Puerto Rico's population increased until early 2000, but it started to drop at an increasing rate since then. Forestland increased dramatically and steadily over the years.

Table 3. Estimated population and forest land changes (ha) from 1969 to 2017

Year	Population (estimated based on US Census)	% Population Change	Forestland (estimated based on our results)	% Forestland Change
1969	2598241	-	133156	-
1974	2925284	12.6	162693	22.2
1978	3146730	7.6	186323	14.5
1982	3332455	5.9	209953	12.7
1987	3514377	5.5	239491	14.1
1992	3640483	3.6	269028	12.3
1998	3718135	2.1	304473	13.2
2002	3725250	0.2	328103	7.8
2007	3683909	-1.1	357641	9.0
2012	3586753	-2.6	387178	8.3
2017	3433782	-4.26	416716	7.6

Restoration efforts to promote forest regeneration in abandoned tropical pastures in Puerto Rico have been an ongoing challenge for scientists. Planting pioneer species in abandoned pastures is one tactic to accelerate forest succession (Aide et al., 1995; Zimmerman et al., 2000). However, there are many barriers inhibiting forest regeneration. Because there was a lack of habitat for animals that disperse many seeds, wind dispersal is most important when trying to reforest pastures in this study site (Zimmerman et al., 2000). Secondary barriers like herbaceous overgrowth and soil nutrients can be altered within restoration practices and are not of large concern for forest regrowth. Therefore, forest recovery in abandoned pastures usually is slow compared with forest recovery following other types of human and natural disturbance (Aide et al., 1995).

In addition, the efforts of the local and federal government with the assistance of non-governmental organizations have contributed to the return of forest to some areas of the island. Numerous local community publications, newspapers, and academic papers have documented events organized by a new generation of Puerto Ricans more aware of environmental issues. One of the most successful community organizations involved in the conservation of Puerto Rico's forests is Casa Pueblo. This entity, originally founded under the name of Workshop of Art and Culture, was established by local residents in the mountain town of Adjuntas to protest government's attempts to bring mining activities to the island's central forests between the 1960s and 1990s (Garcia-Lopez et al., 2017). Some of the areas in central Puerto Rico that have experienced considerable forest cover growth since the 1990s are in lands where Casa Pueblo plants trees and produces coffee.

5. Conclusions

In this study, it was found that forest cover growth in Puerto Rico has continued after 1990 since Rudel et al. (2000)'s research. In the past four decades, forest increased from 15.7% to 45.7%, mainly on abandoned coffee plantations and pastureland. The Landsat images and remote sensing techniques used in this study were effective for forestland change assessment, even though cloud-free imagery for some parts of the island was difficult to find. The satellite-based inventory provided not only changing statistics but also the spatial locations and patterns of forestland conversions. Industrialization and socio-economic development were the major drivers of forest growth in the mountainous and rural areas, while the small amount of forest loss identified was most likely caused by urbanization. The efforts of the local and federal government with the assistance of nongovernmental organizations have also contributed to the forest growth since the 1990s.

The case of Puerto Rico is very complex, as it is the result of the combination of economic, demographic, and cultural factors that are in a constant state of flux. From an ecological perspective, the island's situation needs to be monitored thoroughly in the event that resultant environmental improvement can be used as a model. The information gained and lessons learned during the process can be applied to other densely populated insular tropical territories. The trends of forest recovery that followed the economic transition observed in Puerto Rico are occurring in other regions of the world (Grau et al., 2003). To measure impacts on fragile environments, scientists are employing a number of techniques, information, and methodologies that are going through a fast process of diffusion. It is for these reasons that the experiences of scientists in Puerto Rico monitoring forest structure recovery can serve the needs of those who manage fragile environments in not so distant places, like Haiti, a densely populated country struggling with the collateral damage associated with severe degradation of its forest resources.

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