

Land Use, Population Dynamics, and Land-Cover Change in Eastern Puerto Rico

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Chapter B of

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Abbreviations Used in This Report

km kilometer

km² square kilometer

m² square meter

mm millimeter

WEBB Water, Energy, and Biogeochemical Budgets

Conversion Factors

Multiply	By	To obtain
Length		
millimeter (mm)	0.03937	inch (in.)
kilometer (km)	0.6214	mile (mi)
Area		
square meter (m ²)	10.76	square foot (ft ²)
square kilometer (km ²)	0.3861	square mile (mi ²)

Land Use, Population Dynamics, and Land-Cover Change in Eastern Puerto Rico

By William A. Gould,¹ Sebastián Martinuzzi,² and Isabel K. Parés-Ramos³

Abstract

We assessed current and historic land use and land cover in the Luquillo Mountains and surrounding area in eastern Puerto Rico, including four small subwatersheds that are study watersheds of the U.S. Geological Survey's Water, Energy, and Biogeochemical Budgets (WEBB) program. This region occupies an area of 1,616 square kilometers, about 18 percent of the total land in Puerto Rico. Closed forests occupy about 37 percent of the area, woodlands and shrublands 7 percent, nonforest vegetation 43 percent, urban development 10 percent, and water and natural barrens total less than 2 percent. The area has been classified into three main land-use categories by integrating recent census information (population density per barrio in the year 2000) with satellite image analyses (degree of developed area versus natural land cover). Urban land use (in this analysis, land with more than 20 percent developed cover within a 1-square-kilometer area and population density greater than 500 people per square kilometer) covered 16 percent of eastern Puerto Rico. Suburban land use (more than 80 percent natural land cover, more than 500 people per square kilometer, and primarily residential) covers 50 percent of the area. Rural land use (more than 80 percent natural land cover, less than 500 people per square kilometer, and primarily active or abandoned agricultural, wetland, steep slope, or protected conservation areas) covered 34 percent of the area. Our analysis of land-cover change indicates that in the 1990s, forest cover increased at the expense of woodlands and grasslands. Urban development increased by 16 percent during that time. The most pronounced change in the last seven decades has been the shift from a nonforested to a forested landscape and the intensification of the ring of urbanization that surrounds the long-protected Luquillo Experimental Forest.

Introduction

The island of Puerto Rico is at a geographic and cultural crossroads where human activities are influencing changes in the environment, climate, and land use and land cover. Puerto Rico, which is bordered by the Atlantic Ocean on the north and the Caribbean Sea on the south, lies at the juncture of the Greater and Lesser Antilles (fig. 1). It is in the path of hurricanes and tropical storms approaching the western hemisphere (Salivia, 1972; Weaver, 1986; Scatena and Larsen, 1991, Murphy and Stallard, 2012), atmospheric dust from the African continent (Reid and others, 2003, Stallard, 2012), and distinct air masses arriving from across the Atlantic or from the eastern seaboard of the United States (Malmgren and others, 1998). At a broad scale, these climatic events are controlled by cyclic global climate patterns as well as by human-induced carbon emissions that are changing climate (Huber and Knutti, 2012). At a more local scale, ecosystems respond to a range of environmental conditions and are influenced by historical patterns of changing land use in eastern Puerto Rico.

Eastern Puerto Rico is a good region in which to assess changes in land use and land cover for a number of ecological and social reasons. All six of the Holdridge life zones in Puerto Rico can be found along a transect of less than 15 kilometers (km) between the coast and the upper Luquillo Mountains (Holdridge, 1967; Ewel and Whitmore, 1973). Ecological diversity is affected by natural and human factors and by the strong climatic gradients caused by moisture-laden trade winds rising to pass over the Luquillo Mountains (García-Martinó and others, 1996; Murphy and Stallard, 2012). Mean annual rainfall increases with elevation from about 1,400 millimeters (mm) to about 5,000 mm per year, and mean annual temperature decreases with elevation from about 27.5°C to about 19.5°C along this gradient (Gould and others, 2006). The coastal hills and plains, along with the Luquillo Mountains, form a matrix of ridge, slope, valley, and depression that influences soil moisture, soil development, and vegetation (Weaver, 1991; Basnet, 1992). Long-term climatic trends, aeolian inputs (Reid and others, 2003, Stallard, 2012), storm events (Salivia, 1972; Weaver, 1986; Scatena and Larsen, 1991), climatic gradients, and topographic patterns all help to shape the landscape and control potential vegetation and land cover.

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Figure 1. Location of Puerto Rico and study area, eastern Puerto Rico (see also table 1).

In addition to these complex environmental gradients and dynamics, eastern Puerto Rico has a long history of human activity, and the intensity of land use has differed with time. Pre-Columbian, low-intensity subsistence fishing, farming, hunting, and gathering lasted several thousand years. European colonization and exploitation of forest resources for timber and subsistence agriculture began about 500 years ago and increased slowly for the next three centuries. Intensive farming of sugarcane, tobacco, and coffee for export began more than 200 years ago (Dietz, 1986). The decline in agricultural production and growth of industry during the last six decades shifted much former agricultural land to cattle pasture or to completely abandoned land. Forest is now regenerating on those abandoned lands (Thomlinson and others, 1996; Aide and others, 2000; Chinae, 2002). Recent improvements in infrastructure and transportation systems, increasing population, and the virtual absence of land-use planning strategies have led to the conversion of many former agricultural lands to residential and commercial uses, suburban sprawl (Thomlinson and Rivera, 2000; López and others, 2001; Grau and others, 2003; Martinuzzi and others, 2007), depopulation of urban centers, and urban to suburban migration (Parés-Ramos and others, 2008). Finally, the region has a complex matrix of protected and unprotected areas (Helmer, 2004; Gould and others, 2008) and diverse zoning regulations (Lugo and others, 2000, 2004), which have led to differences in human use and in the responses of the landscape to the history of human activities (Zimmerman and others, 1995; Aide and others, 2000; Thompson, 2002). All of these human activities have had considerable

effect on the land-cover and land-use history of eastern Puerto Rico. The resulting land-use dynamics span a gradient from stable (areas that have maintained relatively consistent land-use intensities (older urban centers, current agricultural areas, mangrove forests, and forested peaks) to dynamic (areas that have fluctuated substantially during the previous 100 years between high- and low-intensity agriculture and agricultural abandonment and, more recently, shifted to urbanization).

Analyses of changes in land use and land cover in eastern Puerto Rico have focused mainly on land cover and change in four areas: (1) within the boundaries of the Luquillo Experimental Forest (whose boundaries match those of El Yunque National Forest) (Crow, 1980; Brown and others, 1983; Scatena, 1989; Weaver, 1990; Foster and others, 1999; Thompson and others, 2002), (2) within the proclamation area (a zone outside the national forest boundary in which the U.S. Congress authorized the U.S. Forest Service to purchase lands for conservation purposes) (Lugo and others, 2000), (3) within the eight municipalities that have jurisdiction of land outside the periphery of the Luquillo Experimental Forest (Thomlinson and others, 1996; Ramos González, 2001; Lugo and others, 2004), and (4) within the four principal watersheds or watershed groups that have all or part of their source in the Luquillo mountains (Ortiz-Zayas and Scatena, 2004) (fig. 1).

In this chapter we assess land use and land cover of the area encompassed by four principal watersheds or watershed groups in eastern Puerto Rico (table 1): Río Grande de Loíza, Río Anton Ruiz to Río Fajardo, Río Herrera to Las Cabezas de San Juan, and Río Maunabo to Río Humacao. These watersheds include four small subwatersheds that are study

Table 1. Watershed, municipality, and national forest areas of eastern Puerto Rico and their percentage of land area in Puerto Rico.

[<, less than]

Region	Area	
	(hectares)	(percent)
Principal watershed or watershed group	161,650	18.1
Río Grande de Loíza watershed	75,098	
Río Anton Ruiz to Río Fajardo watersheds	31,336	
Río Herrera to Las Cabezas de San Juan Coastal watersheds	26,865	
Río Maunabo to Río Humacao watersheds	28,351	
Municipalities surrounding Luquillo Experimental Forest	75,234	8.4
Río Grande	15,747	
Canóvanas	8,552	
Luquillo	6,710	
Fajardo	7,709	
Ceiba	7,429	
Naguabo	13,404	
Las Piedras	8,790	
Juncos	6,893	
Study watersheds	7,346	<1
Cayaguás	2,605	
Canóvanas	2,655	
Icacos	325	
Mameyes	1,761	
El Yunque National Forest proclamation area	22,417	2.5
El Yunque National Forest/Luquillo Experimental Forest	11,429	1.3

watersheds of the U.S. Geological Survey's Water, Energy, and Biogeochemical Budgets (WEBB) program (fig. 1, table 1): Cayaguás, Canóvanas, Icacos, and Mameyes (Murphy and others, 2012). This region occupies an area of 1,616 square kilometers (km²), about 18 percent of the total land in Puerto Rico (table 1). In addition, we describe population dynamics and analyze land-cover changes within the eight municipalities that surround the Luquillo Experimental Forest. This region has been an important area for research and land management because of the regulatory control that the surrounding municipal governments have on development in its periphery. However, a historic lack of enforcement of these regulations has resulted in subsequent building violations (Lugo and others, 2004). Nevertheless, the residents of these municipalities retain a strong interest in and reliance on the ecosystem services of the Luquillo Mountains, particularly as a source of fresh water and recreational opportunities.

Land Cover

A recent land-cover assessment developed by the Puerto Rico Gap Analysis Project identified 70 land-cover types on the island (Gould and others, 2008). Fifty-one of these land-cover types occur within the four principal watersheds of eastern Puerto Rico (table 2). Forest, woodland, and shrubland were the most common land-use types, covering 44 percent of the land area. Thirty-three forest, woodland, or shrubland classes were identified; these classes are based on forest age, degree of canopy cover, underlying substrate, and whether the vegetation is dry, moist, wet, or flooded. Eight dry forest or woodland classes cover about 1 percent of the total area, and they include important eastern dry forests near the coast. Twelve moist-forest types, which cover 25 percent of the area, are primarily composed of the lowland moist forests and woodlands on the lower slopes of the Luquillo Mountains and in the southeastern part of the Río Grande de Loíza watershed. Eleven wet-forest classes, which cover 16 percent of the region, are found on the upper slopes of the Luquillo Mountains (including most of the protected forests within the Luquillo Experimental Forest) and in mountains to the southeast of the Forest. Flooded coastal forests, which cover 1.4 percent of the total land area, include saline mangrove forests and freshwater *Pterocarpus* swamps. Structurally developed forests (in this classification, those forests more than 25 years old) were identified on 1977 imagery (Ramos and Lugo, 1994) in 20 percent of the area.

Six grassland or herbaceous classes, covering 41 percent of the land area of eastern Puerto Rico, include dry and moist pasture and grassland, and seasonally flooded and emergent saline and nonsaline wetlands (table 2). Three developed classes, covering 12 percent of the area, are high-density urban

development (more than 50 percent impervious surface within a 9-hectare area), low-density urban development (more than 50 percent impervious, primarily vegetated, surface within a 9-hectare area), and artificial barrens, which are typically bulldozed areas (table 2; Martinuzzi and others, 2007). The remaining 3 percent of land area consists of natural barrens, agricultural lands other than pasture, and open water.

This detailed classification can be simplified into a set of six classes: forests (closed forest, greater than 60 percent tree cover), woodlands (open forests, 25 to 60 percent tree cover) and shrublands, nonforest vegetation (grasslands and wetlands), natural barrens, urban and artificial barrens (bulldozed areas), and water (fig. 2). Forests occupy about 37 percent of the total land area, woodlands and shrublands 7 percent, nonforest vegetation 43 percent, urban and artificial barrens 12 percent, and water and natural barrens total less than 2 percent (table 3).

Land Use

Eastern Puerto Rico consists of 175 barrios, or neighborhoods, a geographic unit used in the census of population in the U.S. Census every 10 years (U.S. Census Bureau, 2001). This area has been classified into three main land-use categories by integrating recent census information (population density per barrio in the year 2000) with satellite image analyses (relative amount of developed area and natural land cover (Martinuzzi and others, 2007, 2008; Gould and others, 2008). In this analysis, the urban land-use class has greater than 20 percent developed cover within a 1-km² area and population density greater than 500 people per square kilometer. Two rural classes, both with more than 80 percent natural land cover, were identified: a densely populated rural ("suburban") class, which is primarily residential and has more than 500 people per square kilometer, and a sparsely populated rural ("rural") class, which has less than 500 people per square kilometer and is primarily active or abandoned agricultural, wetland, steep slope, or protected conservation areas (Martinuzzi and others, 2007). The urban, suburban, and rural classes cover 16 percent, 50 percent, and 34 percent, respectively, of eastern Puerto Rico (fig. 3, table 4). This is a higher suburban-to-rural ratio when compared with the island as a whole (Martinuzzi and others, 2007). These patterns of population growth and distribution have been controlled by the topography of the island (flat areas are more easily developed), as well as by socioeconomic factors such as sugarcane farming, housing, road networks, and conservation efforts (Grau and others, 2003; Helmer, 2004; Parés-Ramos and others, 2008). Ten percent of eastern Puerto Rico is protected for conservation, compared with an 8 percent average of protected area in the island as a whole (Gould and others, 2008) (fig. 3, table 4).

Table 2. Area of land-cover types in eastern Puerto Rico, from derived analysis of 1999–2003 Landsat ETM+ imagery.

[Gould and others (2008). Land-cover types organized by dominant physiography and climate. <, less than; *, most abundant land-cover types]

Land-cover type	Area	
	(hectares)	(percent)
Total area	161,700	100
Forest, woodland, and shrubland	71,112	44.0
Dry	1,775	1.1
Mature secondary lowland dry alluvial semideciduous forest	135	0.1
Young secondary lowland dry alluvial semideciduous forest	277	0.2
Lowland dry alluvial shrubland and woodland	104	0.1
Mature secondary lowland dry noncalcareous semideciduous forest	329	0.2
Young secondary lowland dry noncalcareous semideciduous forest	666	0.4
Lowland dry noncalcareous shrubland and woodland	246	0.2
Lowland dry riparian forest	14	<0.1
Lowland dry riparian shrubland and woodland	4	<0.1
Moist	40,908	25.3
Mature secondary lowland moist alluvial evergreen forest	362	0.2
Young secondary lowland moist alluvial evergreen forest	1,804	1.12
Lowland moist alluvial shrubland and woodland	1,235	0.8
Mature secondary moist limestone evergreen and semideciduous forest	119	0.1
Young secondary moist limestone evergreen and semideciduous forest	28	<0.1
Moist limestone shrubland and woodland	27	<0.1
*Mature secondary lowland moist noncalcareous evergreen forest	10,352	6.4
*Young secondary lowland moist noncalcareous evergreen forest	18,881	11.7
Lowland moist noncalcareous shrubland and woodland	7,625	4.7
Lowland moist abandoned and active coffee plantations	41	<0.1
Lowland moist riparian forest	241	0.2
Lowland moist riparian shrubland and woodland	193	0.1
Wet	26,126	16.2
Mature secondary montane wet alluvial evergreen forest	180	0.1
Young secondary montane wet alluvial evergreen forest	164	0.1
Montane wet alluvial shrubland and woodland	60	<0.1
Mature secondary montane wet noncalcareous evergreen forest	3,315	2.1
Mature primary tabonuco and secondary montane wet noncalcareous evergreen forest	8,715	5.4
Mature primary palo colorado and secondary montane wet noncalcareous evergreen forest	3,712	2.3
Mature primary sierra palm and secondary montane wet noncalcareous evergreen forest	2,633	1.6
Mature primary elfin woodland and secondary montane wet noncalcareous evergreen cloud forest	257	0.2
Young secondary montane wet noncalcareous evergreen forest	5,315	3.3
Montane wet noncalcareous evergreen shrubland and woodland	1,698	1.1
Montane wet evergreen abandoned and active coffee plantation	77	0.1
Flooded	2,304	1.4
Mangrove forest and shrubland	2,129	1.3
Freshwater <i>Pterocarpus</i> swamp	175	0.1
Grasslands and herbaceous vegetation	66,063	40.9
Dry grasslands and pastures	487	0.3
*Moist grasslands and pastures	58,444	36.1
Seasonally flooded herbaceous nonsaline wetlands	5,620	3.5
Seasonally flooded herbaceous saline wetlands	1,210	0.7
Emergent herbaceous nonsaline wetlands	248	0.2
Emergent herbaceous saline wetlands	53	<0.1
Agriculture	3,223	2.0
Hay and row crops	2,895	1.8
Woody agriculture and plantations	328	0.2

Table 2. Area of land-cover types in eastern Puerto Rico, from derived analysis of 1999–2003 Landsat ETM+ imagery.—Continued

[Gould and others (2008). Land-cover types organized by dominant physiography and climate. <, less than; *, most abundant land-cover types]

Land-cover type	Area	
	(hectares)	(percent)
Natural barrens	444	0.3
Rocky cliffs and shelves	29	<0.1
Gravel beaches and stony shoreline	14	<0.1
Fine to coarse sandy beaches, mixed sand and gravel beaches	214	0.1
Riparian and other natural barrens	45	<0.1
Salt and mudflats	142	0.1
Developed areas	19,542	12.1
*High-density urban development	9,224	5.7
Low-density urban development	7,474	4.6
Artificial barrens	2,844	1.8
Water	1,317	0.8
Freshwater	823	0.5
Salt water	494	0.3

Table 3. Area of simplified land cover in eastern Puerto Rico from derived analysis of recent (1999–2003) Landsat ETM+ imagery.

[From Gould and others (2008); <, less than]

Land-cover type	Area	
	(hectares)	(percent)
Forest	60,157	37
Woodland and shrubland	11,183	7
Nonforest vegetation	68,883	43
Natural barrens	324	<1
Urban and artificial barrens	19,494	12
Water	1,309	1
Total	161,351	100

Table 4. Urban, suburban (densely populated rural), and rural (sparsely populated rural) land-use classes and protected conservation areas in eastern Puerto Rico.

[From Martinuzzi and others (2007); <, less than]

Land-use class	Protected area (hectares)	Unprotected area (hectares)	Total area (hectares)	Percent protected	Percent of 161,401 hectares
Urban	155	25,644	25,809	<1	16
Suburban	2,884	77,283	80,167	4	50
Rural	13,125	42,300	55,425	24	34
Total	16,173	145,228	161,401	10	100

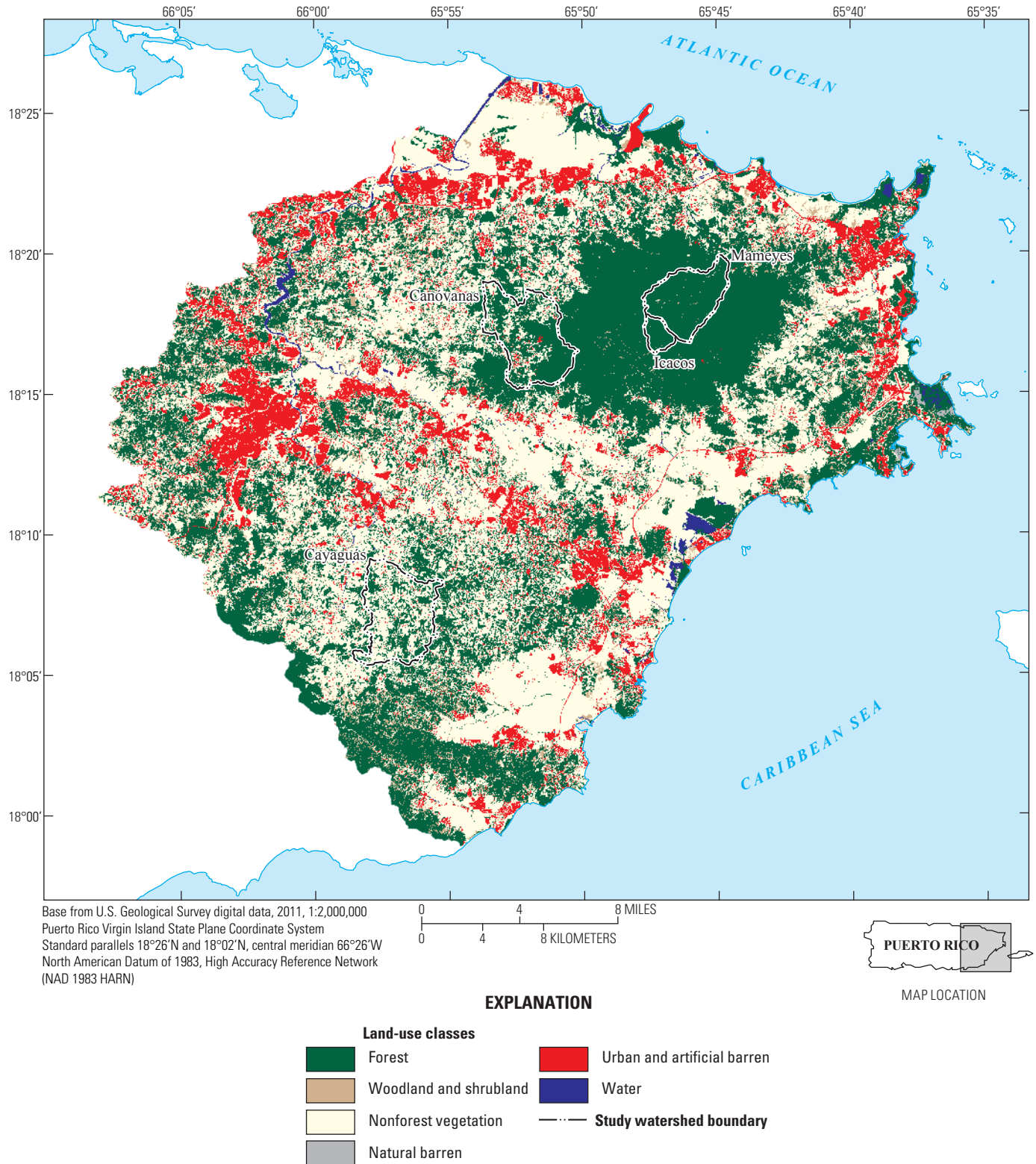


Figure 2. Simplified land cover of eastern Puerto Rico (modified from Gould and others, 2008).

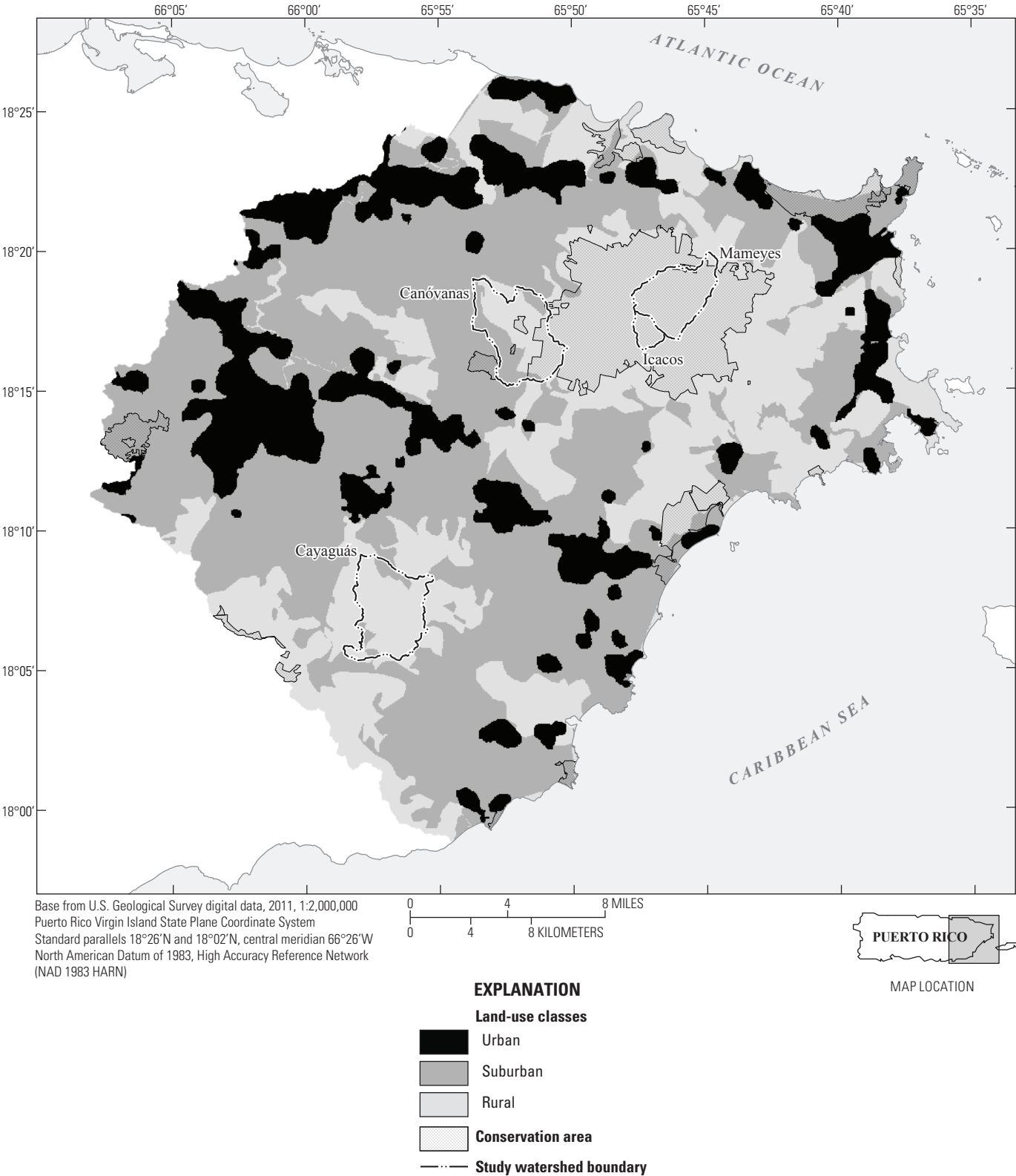


Figure 3. Urban, suburban, and rural land-use classes and protected conservation areas in eastern Puerto Rico (following Martinuzzi and others, 2007).

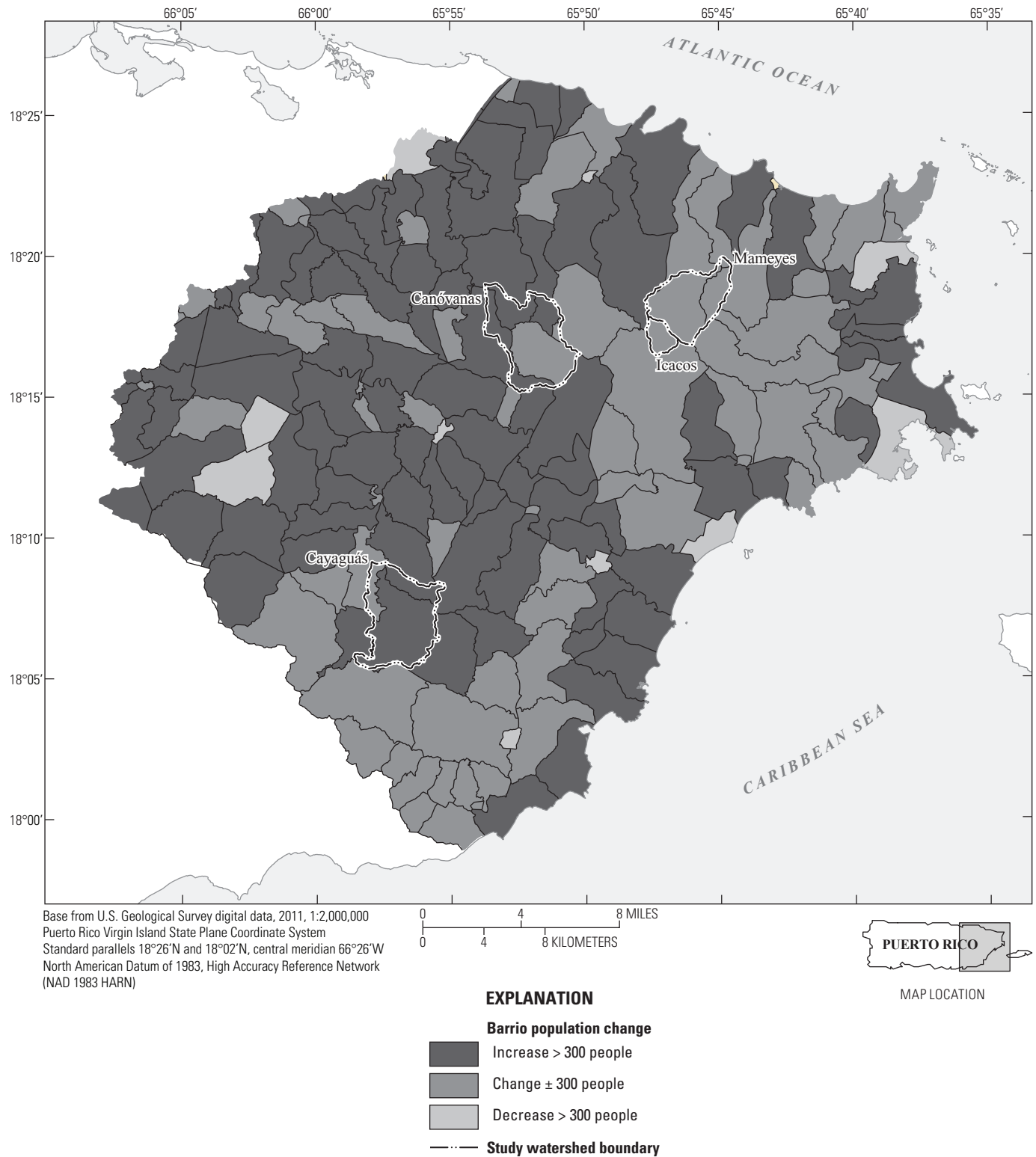


Figure 4. Barrio (neighborhood) population dynamics in eastern Puerto Rico, 1990–2000 (from Parés-Ramos and others, 2008).

Population Dynamics

From 1990 to 2000, overall population trends in Puerto Rico were characterized by an increase in suburban population and housing density, by suburbanization of the rural landscape, and by population decline in several urban centers (Parés-Ramos and others, 2008). In eastern Puerto Rico, only 10 of 175 barrios (6 percent) lost population from 1990 to 2000 (fig. 4), and nine of these barrios were urban. Seventy-three barrios (42 percent) showed little population change (± 300 people) and of these, 42 percent were classified as rural, 40 percent as suburban, and 12 percent as urban barrios. In 92 barrios, population increased markedly (300–6,800 new inhabitants), and of these barrios 9 percent were classified as urban, 77 percent as suburban, and 14 percent as rural. This trend follows the island-wide trend of population increasing in the suburban areas and decreasing in older urban centers outside of the island's main metropolitan area (San Juan), which has occurred mostly at the expense of grasslands (Parés-Ramos and others, 2008). In the past, suburban and urban areas in eastern Puerto Rico were characterized by relatively similar rates of population growth, but recently (1990–2000) there has been a more rapid increase in suburban population density and housing units (fig. 5), influencing land-use patterns in this area.

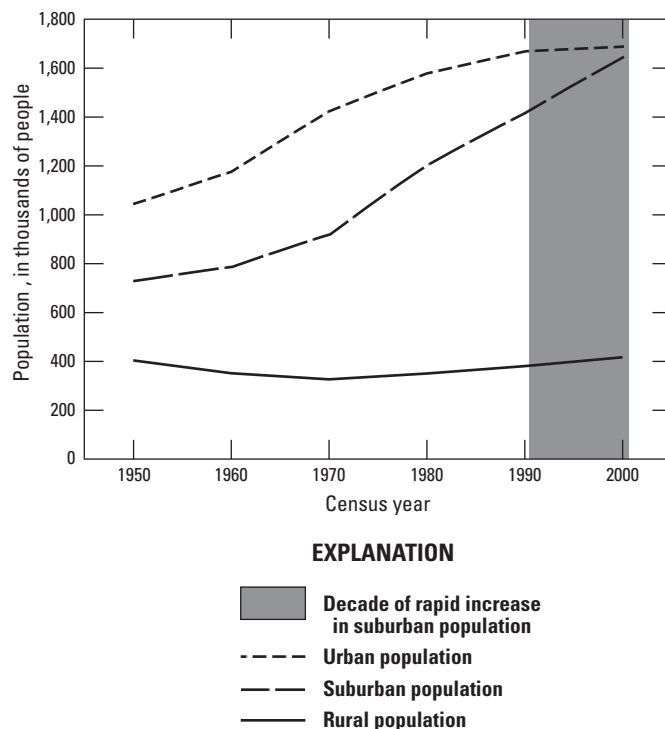


Figure 5. Population trends in land-use categories, 1950–2000, in eastern Puerto Rico.

Land-Cover Change

We compared two recent classifications of land cover to assess land-cover change in eastern Puerto Rico between 1991 (Helmer and others, 2002) and 2003 (Gould and others, 2008). Both assessments are based on the classification of Landsat satellite imagery but differ in methods and classification criteria. The 1991 assessment used a 30-square meter (m^2) pixel resolution, whereas the 2003 assessment used a 15- m^2 pixel resolution. The classification of 1991 imagery has 28 classes for eastern Puerto Rico, whereas the classification of 2003 imagery has 51 classes. The finer resolution of the 2003 classification resulted in areas of residential development (such as houses surrounded by vegetation) to be more precisely delineated, reducing the mapped amount of developed area. Therefore, the 1991 classification overestimates urban areas relative to the 2003 classification. Additionally, geographic representation of mountainous areas in two dimensions always results in distortion of the spatial relationship between land-surface features, and lack of coregistration of pixels between the two classifications may lead to errors. In order to minimize differences in classification schemes, both classifications were reduced to six general classes (see fig. 2) and resampled to 15- m^2 -pixel resolution. Although these differences in methods affect the accuracy of the land-cover change assessment, some inferences about the direction of change in land cover can be drawn from an analysis of a transition matrix of the two classifications.

Our analysis showed that forest cover increased at the expense of woodlands and grasslands, as the trend toward forest regeneration on abandoned land continued (table 5). Urban development (urban and artificial barrens) increased by 16 percent during the period 1991 to 2003. We also assessed long-term land cover by comparing the degree of forest, pasture and agriculture, urban, and mangrove cover in the eight municipalities surrounding the Luquillo Experimental Forest in the years 1936, 1950, 1977, 1995, and 2003 (fig. 6) (Lugo and others, 2004, Gould and others, 2008). We modified the original estimates of urban cover of Lugo and others (2004) for the 1936–1995 classification because of the finer resolution of the 2003 estimate of urban cover. We made the assumption (generally true, but with some exceptions) that once areas were urbanized, they would not revert to natural cover. Therefore, any areas classified as urban in early years, but as natural vegetation in 2003, were changed to that natural cover for all years. The most pronounced change in the last 7 decades has been the shift from pasture and agriculture to a forested landscape and the intensification of the ring of urbanization that surrounds the long-protected Luquillo Experimental Forest (figs. 6, 7).

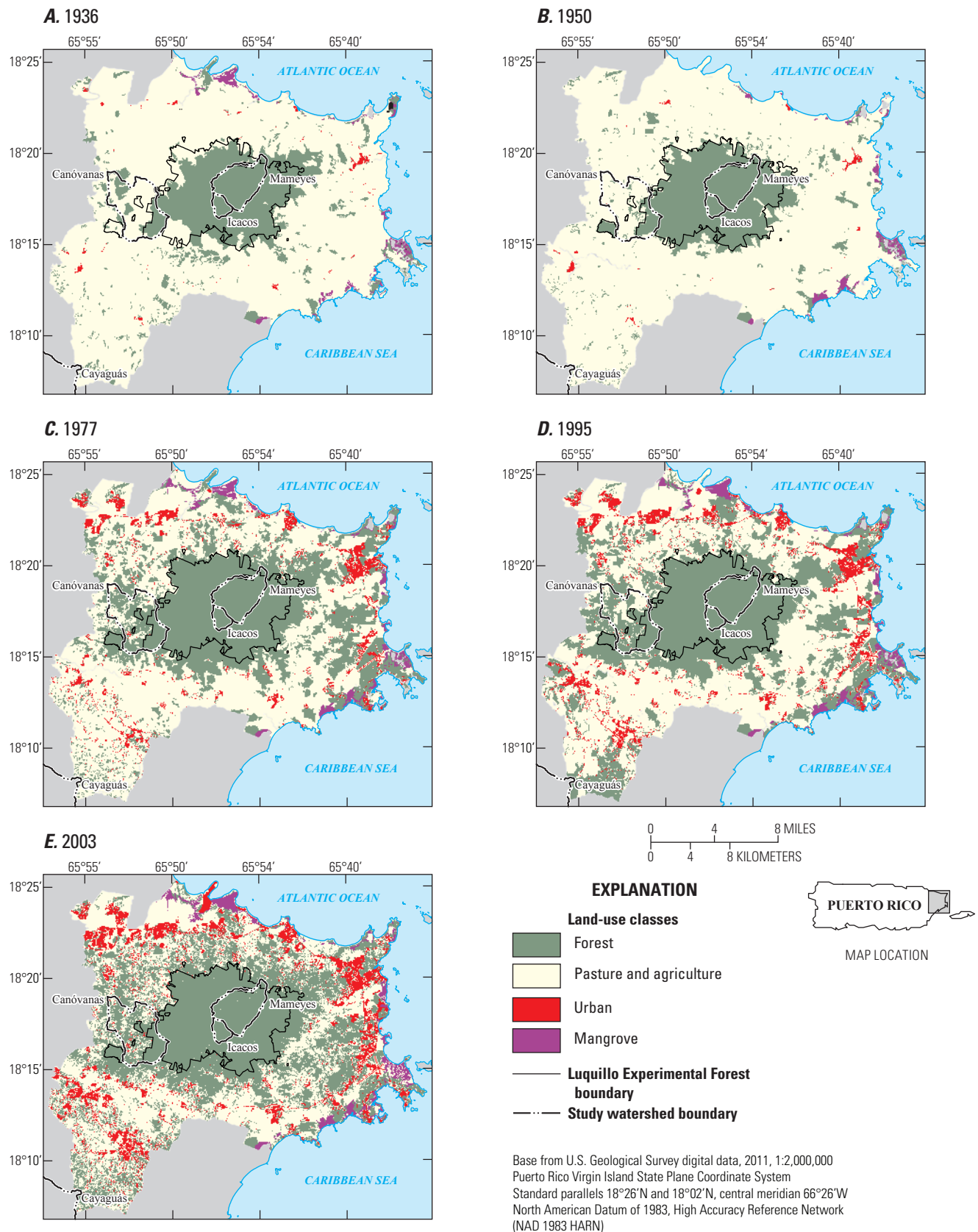
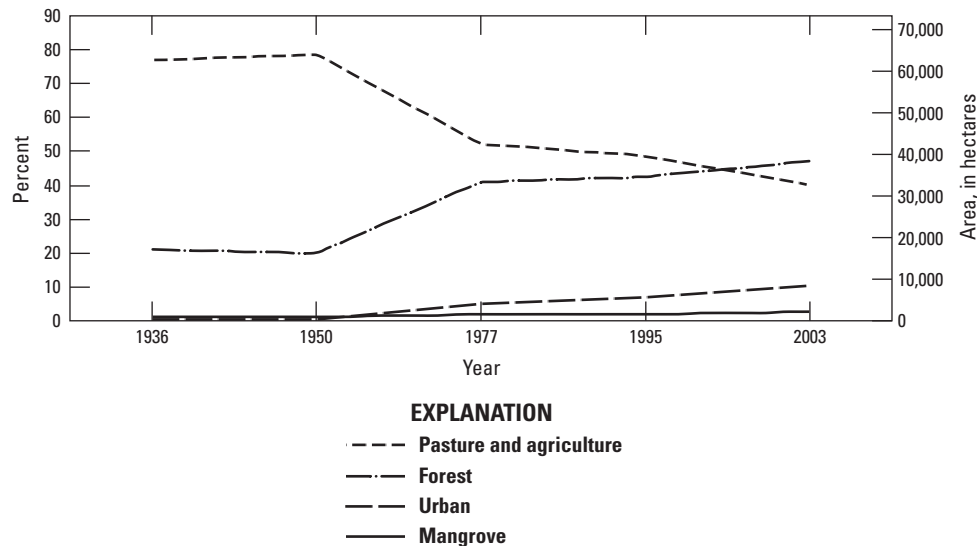


Figure 6. Trends in forest, pasture and agriculture, urban, and mangrove extent, 1936–2003, in eastern Puerto Rico. (Information for years 1936–1995 modified from Lugo and others, 2004.)

Table 5. Land-cover transition matrix of eastern Puerto Rico, 1991 and 2003, based on Landsat satellite imagery analyses for those two years.

[The 1991 classification modified from Helmer and others (2002); 2003 classification modified from Gould and others (2008). Example of how to read matrix: cell in row 1, column 2 states that 1,902 hectares were classified as Forest in 1991 and as Woodland and shrubland in 2003; <, less than]

Land-cover categories, 1991 imagery (hectares)	Land-cover categories, 2003 imagery (hectares)						Total 1991 (hectares)	1991 Percent	Change 1991 to 2003	
	Forest	Woodland and shrubland	Pasture and agriculture	Natural barrens	Urban and artificial barrens	Water			(hectares)	(percent)
Forest	29,011	1,902	5,063	103	1,045	237	37,361	23	22,647	61
Woodland and shrubland	15,086	3,052	8,800	9	1,469	42	28,458	18	-17,335	-60
Pasture and agriculture	14,342	5,407	48,675	80	7,939	458	76,901	48	-8,282	-11
Natural barrens	106	15	165	166	40	20	512	<1	-103	-20
Urban and artificial barrens (developed areas)	1,367	721	5,703	43	8,752	73	16,659	10	2,620	16
Water	96	26	213	7	34	451	827	1	453	55
Total 2003	60,008	11,123	68,619	408	19,279	1,281	160,716	100		
Percent 2003	37	7	43	<1	12	1	100			

**Figure 7.** Diagram of trends in forest, pasture and agriculture, urban, and mangrove extent, 1936–2003, eastern Puerto Rico.

Conclusion

This analysis provides a comprehensive view of land cover, land use, population dynamics, and land-cover change in eastern Puerto Rico. Principal trends in land use and land-cover patterns during the last several decades include a sharp decline in agriculture; the conversion of grassland, woodland, and shrubland to closed forest; and urbanization of the landscape. Land-cover changes differ in their degree of permanence and in their effects on ecosystem services. However, the shift from vegetated natural surfaces to impermeable developed surfaces has stronger and more long-term effects. Not only are impermeable surfaces difficult to restore from an ecological standpoint, they are a result of human investments of time

and capital that represent an inertia difficult to counteract in restoring natural systems. Therefore, the trend towards increasing urbanization in the limited land area of eastern Puerto Rico needs to be assessed in the context of those limitations—that is, which portions of this diverse landscape are being urbanized, what degree of urbanization is desirable, and what ecosystem services are now being lost or may be lost owing to current and future levels of urbanization. An important observation from this analysis is the loss of natural land cover in the coastal areas, highlighting the need to protect the coastal hills and plains and the matrix of habitats that include the mangrove forests and river systems of the coastal area. Additionally, although areas of new forest cover are increasing, little research describes their ecosystem structure or the function of these secondary forests in eastern Puerto Rico.

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