Caribbean Journal of Science, Vol. 43, No. 1, 142-147, 2007
Copyright 2007 College of Arts and Sciences
University of Puerto Rico, Mayagüez

Forests Surrounding the Joyuda Lagoon, Puerto Rico: 67 Years of Change

J. DANILO CHINEA* AND RAMÓN AGOSTO
University of PuertoRico-Mayagüez, Department of Biology, P.O. Box 9012 Mayaguez, PR 00681.
**Corresponding author: jdchinea@yahoo.com*

ABSTRACT.—This study describes forest cover changes and the current vegetation in the area surrounding the Joyuda Lagoon in western Puerto Rico. Forest cover increased from 22 ha to 87 ha between 1930 to 1997. This increase is the result of mangrove forest expansion and the abandonment of a former coconut plantation. Three mangrove species occupy the areas closest to the lagoon water. The abandoned coconut plantation is dominated by several exotic tree species typically planted along the coasts of Puerto Rico. Comparisons with previous accounts of the composition of this plantation and with the vegetation of another abandoned coconut plantation elsewhere in Puerto Rico suggest that this tree assemblage is still developing towards a community type that is very different than that of other areas having similar physical and climatic conditions.

KEYWORDS.—Coastal forests, mangrove, agricultural abandonment, coconut plantation

Puerto Rico's coastal and lowland forests were cleared for agriculture or lumber prior even to European colonization (Wadsworth 1950). Most of Puerto Rico's forest clearing occurred during the 19th century. Such deforestation effects reached a maximum extent (approximately 95% of Puerto Rico's area) during the mid 20th century (Birdsey and Weaver 1985). Aerial

ms. received 14 December 2005; accepted 11 October 2006.

photographs obtained during the 1930s testify to the lack of lowland forests and the degradation of mangrove forests throughout this island. However, the extent of forest cover has increased dramatically during the past half century (Birdsey and Weaver 1985, Grau et al. 2003), with most of this increase being in non-coastal areas. Moreover, with the exception of mangrove, little is known about the structure and composition of the original and current coastal and floodplain forests of Puerto Rico.

Puerto Rico's mangrove forest extent was estimated at 93.48 km^2 prior to 1930 (Heatwole 1985), 67.18 km^2 in the 1960s (Heatwole 1985), and 68.38 km^2 in the early 1990s (Helmer et al. 2002). These values represent a 28% reduction of mangrove area up to the mid-1960s and a slight increase (i.e., approximately 2%) in area from the 1960s to the early 1990s. Although the increased mangrove extent suggested by the most recent estimates is within the classification error of the spectral technique used by Helmer et al. (2002), the forest cover increase documented elsewhere in Puerto Rico suggests that this slight increase may be real.

Abandonment of farming practices, a result of Puerto Rico's sudden shift from an agriculturally-based to an industrially-based society, is given as the main explanation for the counterintuitive recent increase in forest area (Grau et al. 2003). The main agricultural system practiced almost exclusively along the coasts of Puerto Rico, coconut planting, has been almost completely abandoned; a 98% reduction in extent from 5,640 ha in 1935 (Roberts 1942) to 105 ha in 2002 (USDA 2002). Preliminary observations on the east and west coasts of Puerto Rico by the senior author suggest that these abandoned lands are being partially colonized by mangrove trees. This study addresses the following questions: 1. have mangrove and other coastal forest types increased in extent after agricultural abandonment?; 2. if so, what is the tree species composition of these forests? We attempted to answer these questions at a fine spatial scale in the surroundings of the Joyuda Lagoon, a fairly well studied aquatic ecosystem that was surrounded by intensive agricultural activity prior to the 1960s.

The Joyuda Lagoon is located near latitude 18° 8′ 00″ and longitude 67° 10′ 30″, southwest of the town of Mayaguez. It is connected to the Mona Passage through a narrow channel on its southern tip. This lagoon is surrounded by soils of five soil series (Gierbolini 1975). Most of the mangrove forests lie over the Tidal Swamp series that consists of a saline mixture of sandy, clayey, and organic material. The former coconut plantations, mostly on the west side of the lagoon, lie over the Catano sand series, an excessively drained calcareous sandy soil. The northeast side of the lagoon is bordered by the Delicias clay series, a deep, well drained and strongly acid soil derived from serpentinite rocks. There are also very small areas of the Lares clay and Bajura clay series. Elevation throughout most of the studied area ranges from sea level to 2 meters. However, it may reach up to 5 meters on the highest ground of the east side of the lagoon over soils of the Delicias clay series. The study area lies within the Subtropical Moist Forest life zone (Ewel and Whitmore 1973) with a mean atmospheric temperature ranging between 20°C and 26°C and a mean annual precipitation of 1,600 mm (DRNA 2006). The Puerto Rico Planning Board designated the Joyuda Lagoon as a Natural Conservation Area in 1980 (DRNA 2006).

Two sets of aerial photos of the study area from 1930 and 1963 were co-registered to a 1997 set of color aerial photos georeferenced to the State Plane (NAD83 datum) coordinate system. Their pixel sizes were all set to 1 m (i.e., the resolution of the 1997 photos). Land cover types were digitized in ArcMap 8.3. The "Forest" land cover type was considered as those areas having tree crowns covering more than 75% of the area. Areas showing trees at regular distances in a matrix of lighter background (i.e., sandy soils) were considered as "Coconut", and any other land cover types (mostly urban and agricultural) were mapped as "Other" (see Figure 1 and Tables 1 and 2).

Forest cover increased to more than twice its 1930 area. In contrast, the lagoon cover showed a slight decrease (8%) and

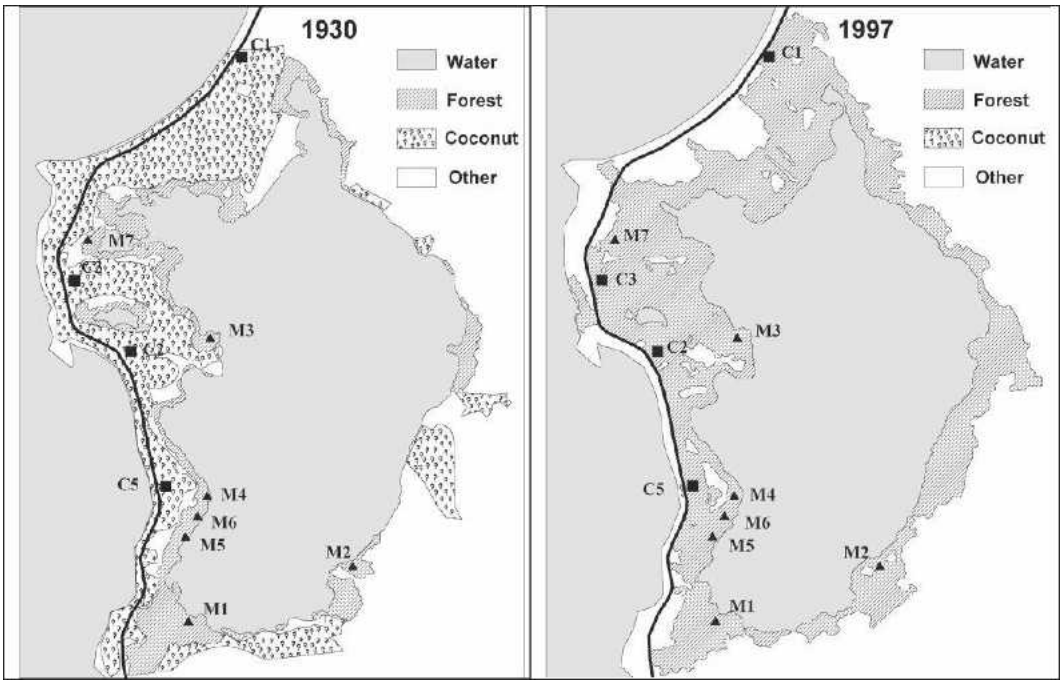

FIG. 1. Cover types surrounding the Joyuda Lagoon in 1930 and 1997. Category "Other" in 1930 was mostly agriculture, while in 1997 it was mostly urban on the west side of the lagoon and agriculture on the eastern side. Black squares indicate plot locations within the abandoned coconut plantation; the black triangles indicate plot locations within mangrove forests. The thick black line along the west coast is Road 102.

TABLE 1. Extent (in ha) of land cover types surrounding the Joyuda Lagoon at three dates. Cover type "Other" mostly includes agriculture and urban.

Cover type	1930	1963	1997
Lagoon surface	144	138	133
Forest	25	46	87
Coconut	62	31	0
Other	153	170	165

the area originally defined as coconut changed into other land cover types (Table 1). Cover changes between 1930 and 1997 (Table 2) included the following: 1. forest expansion into the lagoon; 2. forest expansion within former coconut; 3. forest expansion into the "Other" category; 4. loss of forest to "Other"; and 5. loss of coconut to "Other". Forest expansion was confined primarily to the west edge of the lagoon. Nearly all of this was the result of coconut plantation abandonment. The lower expansion of forest cover along the eastern edge of the lagoon may be due to the prevalence of soils that are more suitable for agriculture than those on the western lagoon edge. While no attempt was made to distinguish cover type changes within the "Other" category, it is evident that large areas have changed into urban cover, particularly on land of the Catano sand series located between the western shore of the lagoon and the coast.

Eleven variable-radius plots were sampled within areas mapped as swamp (N = 7) and coconut plantations (N = 4) in the Mayaguez and Puerto Real topographic maps (USGS 1964 and USGS 1966, respectively). The locations of all samples were decided prior to field work by marking their positions in the digital land cover maps. A GPS receiver was subsequently used to determine their field positions. All mangrove forest samples were located approximately 25 m behind the lagoon edge while all abandoned coconut forest samples were located 25 m east of Road 102 (Figure 1). The diameters (dbh: at 1.3 m from the ground)

TABLE 2. Cover type changes from 1930 to 1997 (in ha). Values in bold along the diagonal indicate areas remaining unchanged; values to the right or left of the diagonal indicate hectares changing from a cover type in 1930 to another cover type in 1997. For example, the first cell below cover type Lagoon in 1930 indicates that 133 ha of lagoon area remained lagoon area in 1997, while the cell below that one indicates that 12 ha of forest grew over the lagoon.

		1930				
		Lagoon	Forest	Coconut	Other	Totals
1997	Lagoon	**133**	0	0	0	133
	Forest	12	**24**	31	22	88
	Coconut	0	0	**0**	0	0
	Other	0	2	31	**132**	165
	Totals	144	26	62	154	**386**

of the closest 20 trees that were also >2.5 cm dbh were measured and identified to species; the distance to the tree farthest from the plot center defined the radius of a plot for the calculation of tree density and basal area. Plot areas ranged from 48 to 201 m^2 on abandoned coconut plantations and between 85 and 278 m^2 on mangrove forests.

Table 3 reveals a clear compositional distinction between areas of mangrove vegetation and areas of former coconut cultivation (as mapped in USGS 1964 and USGS 1966). Possible explanations include the following: 1. highly contrasting distributions of physico-chemical factors in these habitats (e.g., soil water depth and salinity) and the contrasting uses these lands have been subjected to in the recent past (i.e., lumber and fuel wood extraction from mangroves and elsewhere coconut planting with subsequent abandonment), or 2. lack of sufficient sampling to detect compositional changes that are more gradual.

The lagoon edge was a narrow (approximately 10 m wide) red mangrove fringe type forest (not included in our plot sampling). The 12 ha of forest extending into the lagoon (Table 2) suggest that this fringe forest has been developing over the time span of this study. These 12 ha of fringe mangrove expansion into the lagoon represent area that was unforested during 1930. Therefore, the total area of fringe mangrove forest must be even larger than 12 ha. This contradicts Lugo and Musa's (1993) estimate of 9.4 ha of fringe forest for 1985. However, it is possible that the different estimates resulted from different mapping

TABLE 3. Importance values of species in plots. Plot names starting with M were sampled in mangrove areas; those with C in abandoned coconut plantations. Species in bold are non-natives.

	M3	M4	M1	M6	M2	M7	M5	C3	C5	C2	C1
Plot area (m^2)	88	85	191	95	278	95	113	137	62	201	48
Rhizophora mangle	100		3	63	77						
Avicenia germinans		100	97	37		54	90				
Laguncularia racemosa					23	46	10				
Cocos nucifera								**26**	**15**	**66**	
Terminalia catapa								**43**	**14**	**4**	**3**
Swietenia mahagoni								**11**			
Delonix regia									**22**		
Thespesia populnea									**46**		
Cassia siamea											**91**
Callophylum calaba								6			3
Bursera simaruba								15			
Tabebuia heterophyla									3		
Annona glabra										30	
Chrysobalanus icaco											3

methods or from an additional expansion between 1985 and 1997.

Behind the fringe forests were basin mangrove forests dominated by different mixtures of the three mangrove species of Puerto Rico. Five of the 7 possible combinations of these three species were found in our plots (with the exceptions of the mixture of the three mangrove species and white mangrove monoculture) (Table 3). All basin mangrove forests sampled showed evidence of a major disturbance, such as large, uprooted trees and numerous multiple-stemmed trees, likely the result of disturbances generated by Hurricane Georges in 1998. Lugo and Musa (1993) associated the presence of freshwater runoff and topographic position with mangrove species composition but lamented that substantial compositional variation could not be accounted for by these or other measured factors. Although below ground environmental variability may help to explain such compositional variability, it is also possible that major disturbances, such as hurricanes, leave a long lasting mark in the composition of these stands, all of which occur within fairly small areas regardless of prevailing environmental conditions. On this point, it is notable that Smith et al. (1994) cite two reports of Florida mangrove stands failing to recover their pre-tropical storm damage composition.

The stands in abandoned coconut plantations were also quite variable. Only one (*Terminalia catapa*) of eleven tree species was present in all plots. A clear characteristic of these stands is their being dominated by exotic species. This is the case even though coconut, the commercial species planted originally, is dominant in just one of the 4 stands. The most distinct stand, dominated by the ornamental *Cassia siamea*, did not include mature coconut trees. This may reflect recent clearance and subsequent abandonment of this site. The exotic species in these stands are commonly planted along roadsides and house patios near the coast. The native species *Callophylum calaba* and *Tabebuia heterophyla* are also common ornamentals (Schubert, 1979). Judging by the small variability in soils and topography, particularly in the west side of the lagoon, it is unlikely that such factors explain most of the compositional variability. An alternative explanation may be that different plots are closest to a different set of species that serve as seed sources for colonizers.

Pérez Ramírez et al (1981), in a study of the entire Joyuda Lagoon watershed, found only four of the 11 tree species that we found in our coconut plots. In addition, they found six tree species within the coconut plantations that we did not find in our plots. However, we found four tree species, all exotic ornamentals, that they did not find anywhere within their study area. These comparisons suggest that the tree communities in the surroundings of this lagoon are changing. However, Pérez Ramírez et al. (1981) did not sample these forests and did not provide any information about the sizes or abundances of these species. Therefore, this inference must be evaluated again after future sampling of our plots.

Figueroa et al. (1984) described the vegetation of an abandoned coconut plantation at a site within the same life zone and similar edaphic conditions (i.e., coastal sandy soils) on the north central coast of Puerto Rico, more than 70 kilometers northeast of the Joyuda Lagoon. Except for coconut, the species composition at that site is completely different from that at Joyuda. In addition to coconut, they found four native tree species in two 100 m^2 plots, none of which were documented either by Pérez Ramírez et al. (1981) or our investigation into the surroundings of the Joyuda Lagoon. These comparisons lead us to infer that the communities being assembled after the abandonment of coconut planting may result more from the availability of propagules than from a match of species and habitat. Further monitoring of these plots, determination of the nearest source of propagules, and a more detailed sampling of habitat conditions will clarify whether our inferences are correct.

Acknowledgments.—Luis E. Almodovar Rodríguez, José I. Cancel Vélez, and Juan C. Benavides helped with sampling mangrove

vegetation. The Puerto Rico Roads Authority provided the 1963 aerial photos.

Literature Cited

Birdsey, R. and P. Weaver 1985. The forest resources of Puerto Rico. Resource Bulletin SO-85. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, 59 p.

DRNA 2006. Reserva Natural Laguna Joyuda, Cabo Rojo. Puerto Rico Department of Environment and Natural Resources. http://www.gobierno.pr/DRNA/ReservasNaturales/LagosRiosLagunas/LagunaJoyuda/La guna_JoyudaI.htm

Ewel, J. J., and J. L. Whitmore. 1973. The ecological life zones of Puerto Rico and the US Virgin Islands. Res. Pap. ITF-18. USDA, Forest Service, Institute of Tropical Forestry, 72 p.

Figueroa, J. C., L. Totti, A. E. Lugo, and R. O. Woodbury. 1984. Structure and composition of Moist Coastal forests in Dorado, Puerto Rico. USDA, Forest Service, Research Paper SO-202.

Gierbolini, R. E. 1975. Soil Survey of Mayaguez of Western Puerto Rico. US Department of Agriculture, Soil Conservation Service.

Grau, H. R., T. M. Aide, J. K. Zimmerman, J. R. Thomlinson, E. Helmer, and X. Zou. 2003. The ecological consequences of socioeconomic and land-use changes in postagriculture Puerto Rico. Bioscience 53:1159-1168.

Heatwole, H. 1985. Survey of the mangroves of Puerto Rico: a benchmark study. Caribb. J. Sci. 21(3-4): 85-99.

Helmer, E. H., O. Ramos, T. Del M. López, M. Quiñones, and W. Diaz. 2002. Mapping the Forest Type and Land Cover of Puerto Rico, a Component of the Caribbean Biodiversity Hotspot. Caribb. J. Sci. 38:165-183.

Lugo, A. E., and J. C. Musa. 1993. Mangroves of Laguna Joyuda. Acta Científica 7:67-90

Pérez Ramírez, M. A., del Llano, and M., Laboy, C. 1981. Suplemento técnico para la reserva natural Laguna Joyuda y terrenos asociados. Departamento de Recursos Naturales, Estado Libre Asociado de Puerto Rico.

Roberts, R. C. 1942. Soil survey: Puerto Rico. USDA, Bureau of Plant Industry. Series 1936, No. 8.

Schubert, T. H. 1979. Trees for Urban Use in Puerto Rico and the Virgin Islands. General Technical Report SO-27.New Orleans, LA: U.S. Dept. of Agriculture, Forest Service, Southern Forest Experiment Station. 91 p.

Smith, T. J., M. B. Robblee, H. R. Wanless, and T. W. Doyle. 1994. Mangroves, hurricanes, and lightning strikes. Bioscience 44:256-262.

USDA 2002. 2002 Census of Agriculture: Puerto Rico. USDA, National Agricultural Statistics Services. AC-02-A-52.

USGS 1964. Mayaguez Quadrangle, Puerto Rico. 1: 20,000; 7.5 minute series topographic map. US Geological Service.

USGS 1966. Puerto Real Quadrangle, Puerto Rico. 1: 20,000; 7.5 minute series topographic map. US Geological Service.

Wadsworth, F. W. 1950. Notes on the climax forests of Puerto Rico and their destruction and conservation prior to 1900. Caribbean Forester 11:38-47.