FINAL STATE PROJECT REPORTS

Puerto Rico Gap Analysis Project

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Introduction

The Puerto Rico Gap Analysis Project (PRGAP) began in 2001 to assess Puerto Rico's land cover, vertebrate distributions, land stewardship, and gaps in the conservation of vertebrate species and habitats. The project was instigated by Dr. Jaime Collazo, Assistant Unit Leader, North Carolina Cooperative Fish and Wildlife Research Unit and Professor of Zoology and Forestry at North Carolina State University (NCSU) and has been led by the U.S. Department of Agriculture (USDA) Forest Service International Institute of Tropical Forestry in collaboration with the Puerto Rico Department of Natural and Environmental Resources and NCSU (Gould et al. 2007). PRGAP is based on methods developed by the National Gap Analysis Program to determine the degree to which animal species and natural communities are represented in the current mix of conservation lands. Those species or communities not well represented are considered conservation "gaps." The purpose of PRGAP is to provide geographic and ecological information on the status of the terrestrial vertebrate species and habitats of Puerto Rico. This provides land managers, government planning and policy makers, scientists, students, and the general public with information to make better decisions regarding land management and conservation.

PRGAP has four major components: land cover mapping, documentation of vertebrate species distributions, documentation of land stewardship practices with respect to conservation, and an integrated analysis of these three elements. A number of research publications, reports, and maps have been derived from PRGAP (Gould et al. 2006; Gould et al. 2007; Martinuzzi et al. 2007a–c; Vierling et al. 2007; Gould et al. 2008a–d; Martinuzzi et al. 2008a–c; Parés-Ramos et al. 2008).

Land Cover

We developed a land cover map of Puerto Rico using recent (1999–2003) satellite imagery and information on climate, geology, topography, hydrology, and land use history. We defined 70 land cover classes in a hierarchical classification scheme based on whether the cover was natural vegetation, developed, or agricultural, and on whether the natural vegetation was closed forest, woodland, shrubland, or grassland. Forest and grassland classes were further defined as dry, moist, wet, or flooded. These units were then differentiated as occurring on soils derived from limestone, alluvial, serpentine, or noncalcareous substrates. A number of forest types are further classified as to the forest age (i.e., primary, mature secondary, or young secondary forests). Wetlands were classified as forested or herbaceous, saline or nonsaline, and seasonally flooded or emergent. Finally, where information was available we described the dominant plant communities and species representative of these land cover units.

We classified 53 percent of Puerto Rico as predominantly woody vegetation, 35 percent as grassland or herbaceous agriculture, 11 percent as developed land, and about 1 percent each of water and natural barrens (Table 1). Of the woody areas, low and mid elevation moist forests cover 26 percent, upper elevation wet forests cover 18 percent, dry forests cover 7 percent, and flooded mangrove and *Pterocarpus* forests cover 1 percent of the island. Coastal wetlands cover less than 4 percent of the island. Forty-two percent of the wetlands are saline and 58 percent are freshwater. Mangroves and *Pterocarpus* swamps cover 1 percent of the island, 67 km^2 and 2.6 km^2 respectively. Seventy-four percent of the wetlands are dominated by herbaceous vegetation, and 92 percent of these are seasonally flooded. Of the herbaceous wetlands, 77 percent are nonsaline and 23 percent are saline.

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Table 1. Simplified land cover classes from the Puerto Rico Gap Analysis Project land cover mapping.

Land cover	Area		Estimated number of samples	Final number of samples
	Hectare	Percent		
Forest (except mangrove)	345,132	39	125	125
Woodland and shrubland	117,974	13	43	43
Mangrove	8,700	1	3	20
Grassland, pasture, agriculture	312,664	35	113	113
Urban and barren	101,845	11	37	37
Water	8,540	1	3	20
Total	**894,855**	**100**	**324**	**358**

Land Cover Accuracy Assessment

We used island-wide 1-m^2 resolution color IKONOS imagery from 2001–02, including Vieques, Culebra, Mona, and the smaller cays to evaluate the thematic accuracy of the PRGAP land cover map. We concluded that the accuracy assessment should be conducted on the six original classes obtained through the unsupervised classification as they represented the main classes originally separated spectrally. The final 70 PRGAP land cover units were created through modeling of the original classes in combination with geological, climatological, and other auxiliary data. Furthermore, the recoded six land cover classes simplified the accuracy assessment process and helped to reduce image interpretation errors when using the reference IKONOS imagery.

Three hundred fifty-eight sample points were randomly allocated within each of the six land cover classes. Image interpreters did not know which points had been assigned to which classes and the corresponding reference sample points were assessed in the IKONOS imagery and allocated to one of the six classes. ERDAS imagine 9.0 was used to generate an error matrix, accuracy totals, and kappa statistics.

The land cover accuracy assessment (Tables 2 and 3) shows an overall accuracy of 84.92 percent and a kappa value of 0.8, which indicates substantial agreement (Landis and Koch 1977). However, there is significant variability in the producer's and user's accuracy. The producer's accuracy (PA) relates to the probability that a reference sample (IKONOS-interpreted land cover class) will be correctly mapped and measures the errors of omission, whereas the user's accuracy (UA) indicates the probability that a sample from the land cover map matches the reference data and measures the error of commission. The producer's accuracy ranges from 52.54 to 100 percent and the user's accuracy ranges from 72.09 to 95 percent (Table 3). Overall, accuracy assessment for five of the six recoded tended to be in a similar range, from 87 to 100 percent for the producer's accuracy and from 82 to 95 percent for the user's accuracy. However, for the open forest and shrubland class, the PA decreased to 52 percent and the UA decreased to 72 percent, indicating a degree of misclassification. With any land cover classification produced from satellite imagery, misclassification often results from subpixel spatial variability and spatial and spectral resolution limitations.

Table 2. Error matrix of IKONOS-based accuracy assessment of the Puerto Rico Gap Analysis Project major land covers classes.

[Reference data are from IKONOS 2001–02 imagery. The number of correctly identified pixels is in the diagonal part of the matrix and mis-identified pixels are in the row or column of the land cover type in which they occur in the IKONOS imagery]

Land cover class	Error matrix						Total number of pixels
	(1)	(2)	(3)	(4)	(5)	(6)	
(1) Forest (except mangrove)	**108**	9	0	6	2	0	**125**
(2) Woodland and shrubland	8	**31**	0	3	1	0	**43**
(3) Mangrove	0	0	**19**	0	0	1	**20**
(4) Grassland, pasture, agriculture	2	16	0	**93**	2	0	**113**
(5) Urban and barren	0	2	0	1	**34**	0	**37**
(6) Water	0	1	0	0	0	**19**	**20**
Total	**118**	**59**	**19**	**103**	**39**	**20**	**358**

Table 3. Accuracy of land cover classifications of the Puerto Rico Gap Analysis Project.

[**Abbreviations**: RT, reference pixels; CT, classified pixels; NC, number pixels correctly classified; PA, producer's accuracy (samples correctly mapped); UA, user's accuracy (mapped point matches data)]

Land cover class	RT	CT	NC	PA	UA	Kappa
				(percent)		
Forest (except mangrove)	118	125	108	91.53	86.40	0.7971
Woodland and shrubland	59	43	31	52.54	72.09	0.6659
Mangrove	19	20	19	100.00	95.00	0.9472
Grassland, pasture, agriculture	103	113	93	90.29	82.30	0.7515
Urban and barren	39	37	34	87.18	91.89	0.9090
Water	20	20	19	95.00	95.00	0.9470
Total	**358**	**358**	**304**			
Overall Kappa statistics (KHAT value)						**0.8007**
Overall accuracy (percent)					**84.92**	

Terrestrial Vertebrate Distributions

More than 470 vertebrate species have been recorded in Puerto Rico and its adjacent islands including terrestrial and aquatic birds, reptiles, amphibians, and mammals. Of these, 426 are terrestrial vertebrate species. Many of these species are migratory, wintering, accidental, or vagrant species that do not breed regularly or at all on the island. We have developed a database that contains taxonomic information, residence status, and conservation status of all these species. We predicted the distributions of 98 bird, 47 reptile, 18 amphibian, and 14 mammal species including all native resident endemic and endangered terrestrial vertebrates and some introduced species (Figure 1).

Species ranges were mapped by using a network of 24-km^2 hexagons that cover Puerto Rico and its adjacent islands. Each hexagon was attributed with the species probability of occurrence in one of eight categories. Species probability of occurrence information is derived from published literature, unpublished data sets, museum records, and expert opinion.

Species distributions were mapped by identifying predicted habitat within the species range based on literature and expert review. The resulting maps of predicted species distribution are a result of the integration of information from the vertebrate database and land cover mapping. We combined species distribution information to develop species richness maps. The resulting biodiversity patterns indicate that forested parts of the landscape are the habitats with the highest predicted species richness, (i.e., in our analyses forested habitats have higher *alpha* diversity than other habitats) (Figure 2). Urban and barren areas are the habitats with the lowest species richness. Individual taxonomic groups show distinct patterns.

We also looked at the species richness within the network of 24-km^2 hexagons used to document species occurrences. This analysis indicates that the highest levels of habitat heterogeneity (*beta* diversity) and resulting biodiversity are in coastal areas with a mix of wetlands, grassland, and forested coastal hills (Figure 3). The coastal area is also extremely vulnerable to development, because the topography is less steep, it is close to urban areas and existing infrastructure, and nonwetlands on the coastal plain and coastal hills are primarily unprotected. Development is prohibited in the wetlands, but development adjacent to wetlands can destroy the diverse matrix of habitats and affect hydrologic patterns, altering species composition and biodiversity.

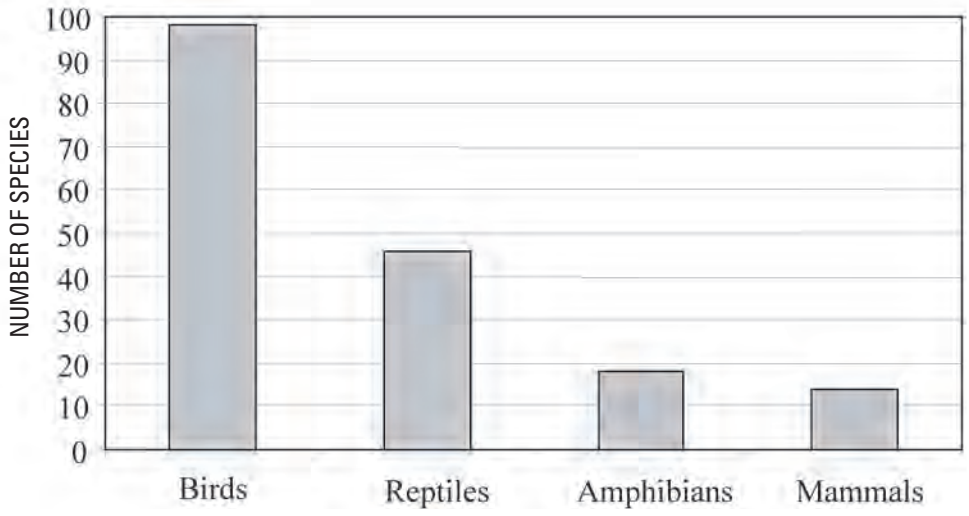

Figure 1. Terrestrial vertebrate species by taxonomic group included in the Puerto Rico Gap Analysis Project.

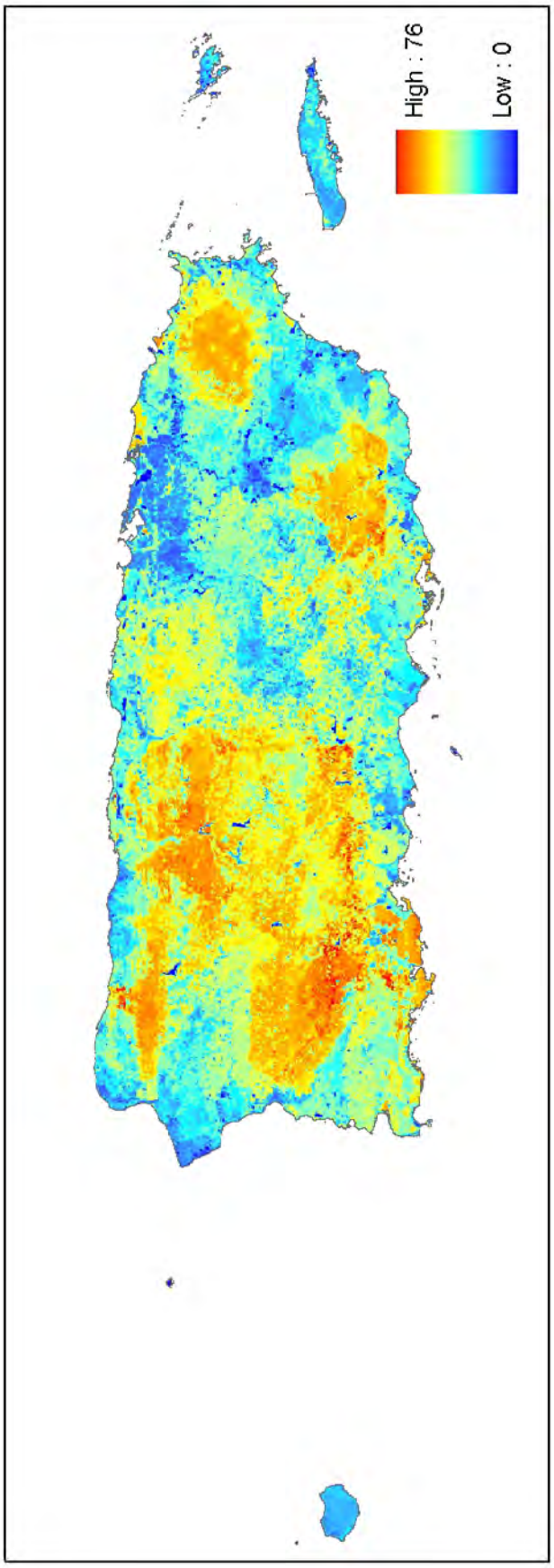

Figure 2. Predicted terrestrial vertebrate species richness per 15 m pixel (225 m^2).

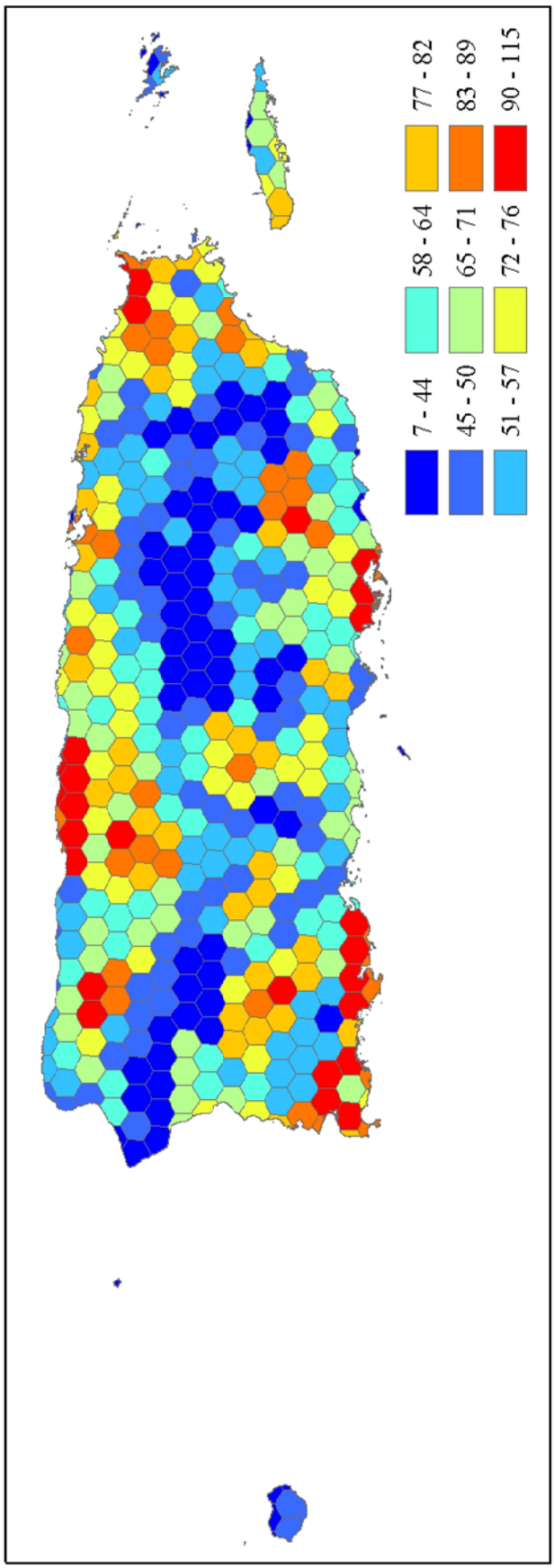

Figure 3. Predicted terrestrial vertebrate species richness per 24 km^2 hexagon.

Land Stewardship

The national GAP currently uses a scale of 1 to 4 to denote relative degree of maintenance of biodiversity for stewardship areas. A status of "1" denotes the highest, most permanent level of maintenance, and "4" represents the lowest level of biodiversity management, or unknown status (Scott et al. 1993).

Although land stewardship, management, and land use are very dynamic, we have identified 77 stewardship areas that receive some management for conservation (GAP status 1 through 3). Land ownership of these areas is shared among 20 organizations with the Puerto Rico Department of Natural and Environmental Resources (DNER) being the primary landowner. Management of land stewardship areas is shared among 20 organizations with the DNER, the U.S. Forest Service, and the U.S. Fish and Wildlife Service being the primary governmental land managers and the Conservation Trust of Puerto Rico being the primary nongovernmental land manager (Figure 4).

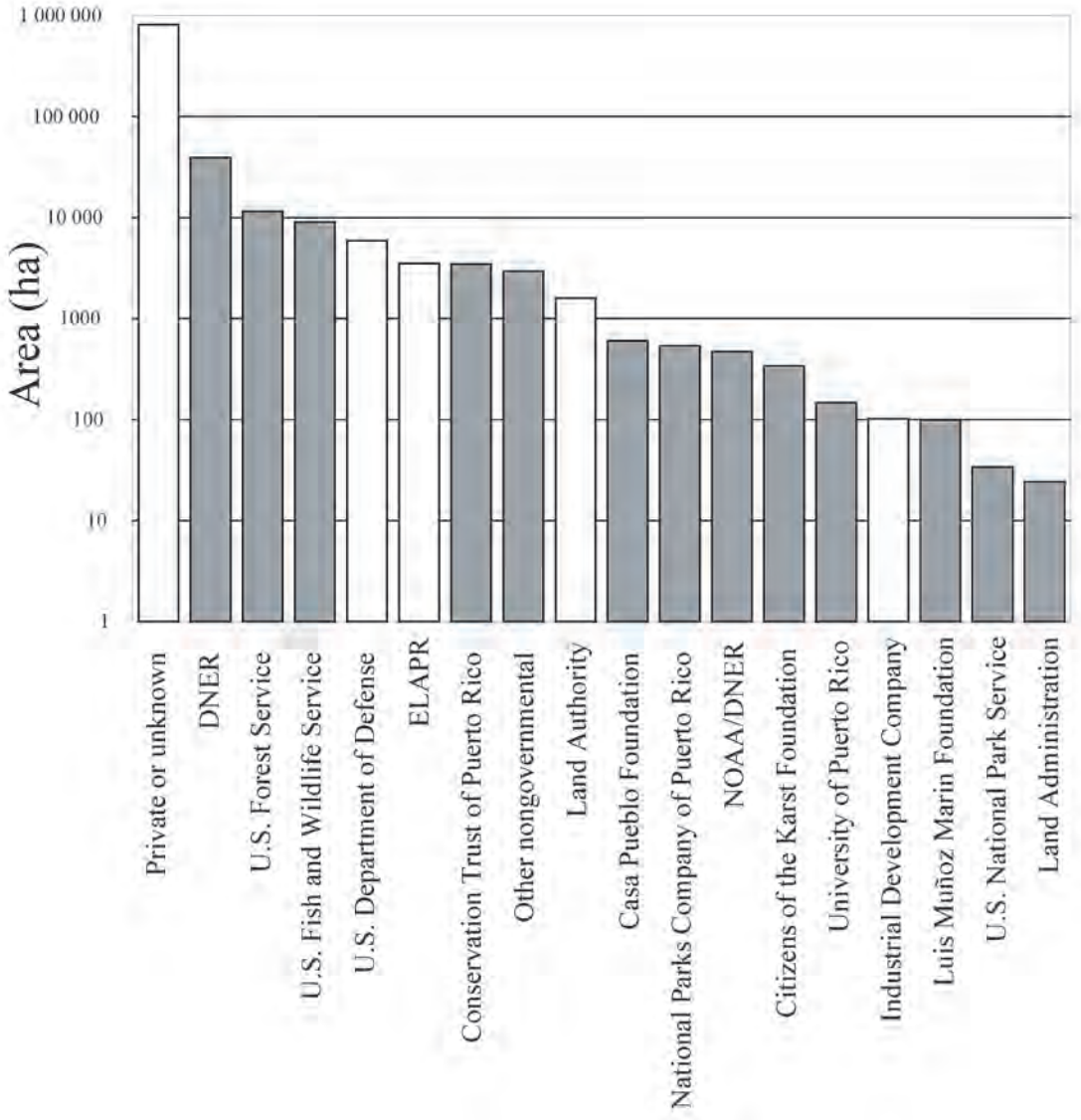

Figure 4. Primary land managers and number of hectares managed in Puerto Rico under GAP management status 1, 2, 3, or 4. Entities with clear bars have no management for conservation (GAP status 4). Entities with dark bars are in part or completely managed for conservation (GAP status 1 through 3). Note the scale is logarithmic. DNER, Puerto Rico Department of Natural and Environmental Resources; ELAPR, Estado Libre Associado de Puerto Rico (the commonwealth government); NOAA, National Oceanic and Atmospheric Administration.

Of the total land area of Puerto Rico, 7.6 percent receives some management for conservation (GAP status 1, 2, or 3) with 7.4 percent of the total land area receiving good management of conservation (GAP status 1 or 2).

Fifty-nine percent of the stewardship areas are managed by Commonwealth agencies, 30 percent by Federal agencies, and 11 percent by nongovernmental or private agencies (Figures 5 and 6).

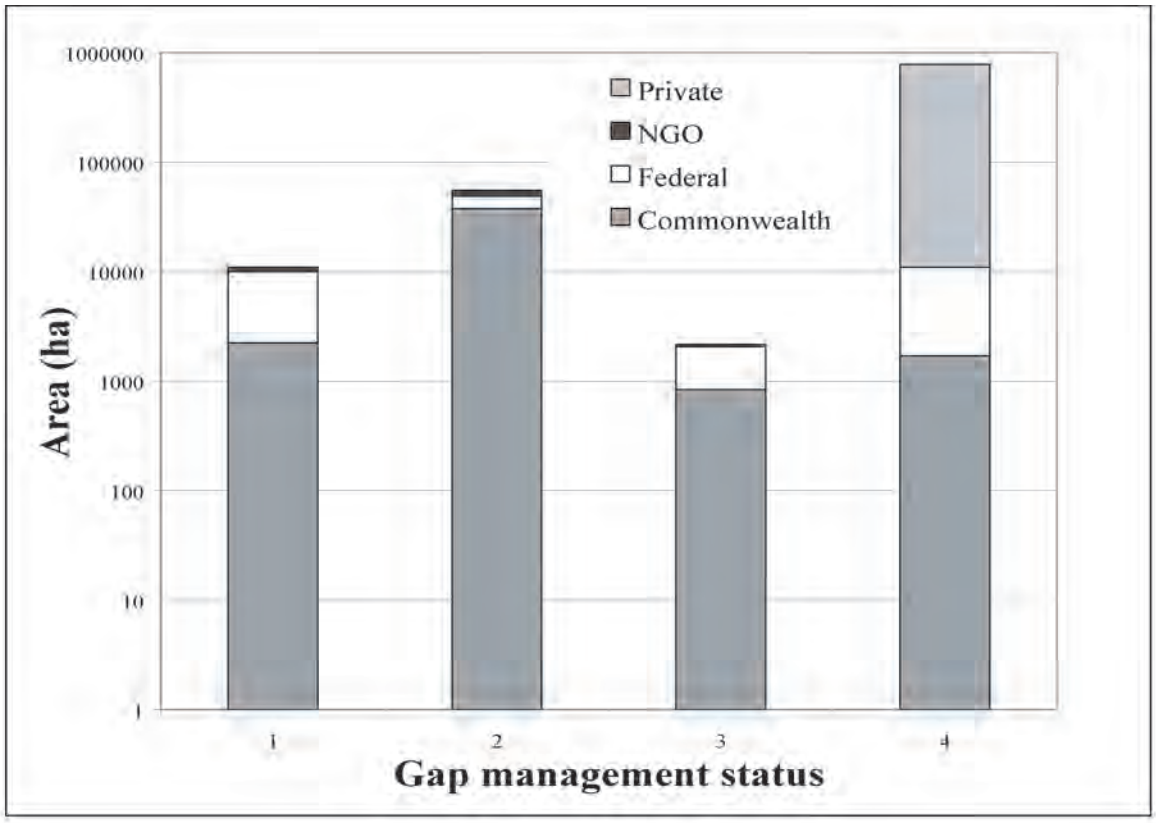

Figure 5. Number of hectares and managing agencies in GAP status 1, 2, 3, and 4 for Puerto Rico. Note scale is logarithmic. NGO, nongovernmental organization.

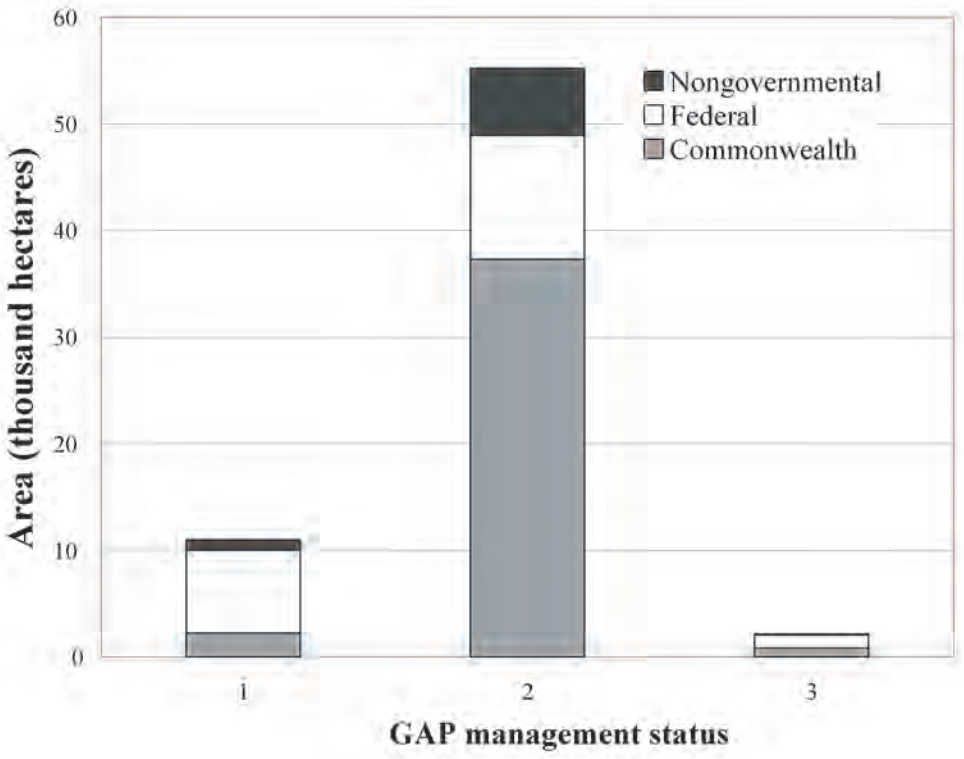

Figure 6. Number of hectares by managing agencies of areas with some management for biodiversity conservation (GAP status 1 through 3).

Gap Analyses–Land Cover

Eight of the 70 land cover classes have less than 1 percent of their area represented in GAP status 1 or 2 conservation areas and cover 43 percent of the island. The conservation areas are primarily subject to human use such as agriculture, housing, and other development. Moist grasslands and pastures cover nearly one-quarter of the island and are primarily active pasture and abandoned agricultural land. Given the resilience of the natural vegetation in Puerto Rico, this land cover type has potential for management for reforestation or as natural grasslands and open space.

Twenty-seven land cover classes have between 1 and 10 percent of their area represented in GAP status 1 or 2 conservation areas. These land cover classes account for 44 percent of the island. They range from an extent of less than 1 percent to more than 6 percent of the island and include a number of young secondary forest and woodland land cover classes, as well as artificial and natural barrens, active and abandoned shade coffee plantations, dry grasslands and pastures, riparian forests, and four mature secondary forest classes.

Four land cover classes have between 10 and 20 percent of their area represented in GAP status 1 or 2 conservation areas. These land cover classes account for 1.7 percent of the island and include two woodland-shrubland classes that typically occur on abandoned agricultural land, dryland riparian forest, and palm plantations.

Fourteen land cover classes have between 20 and 50 percent of their area represented in GAP status 1 or 2 conservation areas and account for 6.1 percent of the island's total area. They include a number of ecologically important areas including beaches and shorelines, mature forests, wetlands, mangrove complexes, and Sierra palm forest.

Seventeen land cover classes are over 50 percent protected under GAP status 1 and 2. They account for 5.1 percent of the island. They include important primary and mature secondary forest types in the Luquillo Mountains, freshwater *Pterocarpus* swamps, forests on serpentine substrates, and a number of dryland habitats unique to Mona Island and the Guánica Biosphere Reserve.

Gap Analyses—Vertebrates

Four species have less than 1 percent of their habitat protected under GAP status 1 or 2. These include two species of gecko common in urban areas, one bird, *Carduelis cucullata,* which is non-native, and *Eleutherodactylus cooki*, the guajón or rock coqui, which has limited habitat none of which is protected.

One recently discovered species not fully included in the PRGAP analysis is the coqui llanero, or plains coqui (*Eleutherodactylus juanariveroii*) (Ríos-López and Thomas 2007). Its habitat is currently unprotected.

Seventy-seven species have 1 percent to less than 10 percent of their habitat protected under GAP status 1 or 2. Many of these unprotected species are widespread although not necessarily common and occur in disturbed habitats. A few, such as the blind snake *Typhlops platycephalus*, have limited habitat (15 percent of the island) and the majority of that habitat (98 percent) is unprotected.

Thirty-two species have 10 percent to less than 20 percent of their habitat protected under GAP status 1 or 2. These species are a mix of those with widespread and those with limited habitat extent.

Forty-three species have 20 percent to less than 50 percent of their habitat protected under GAP status 1 or 2. All these species have habitat extent limited to less than 11 percent of the island. A number of endangered species are in this group, and many are limited to less extensive habitats such as saline and freshwater ponds and wetlands or high mountain areas.

Twenty-one species have at least 50 percent of their predicted habitat protected under GAP status 1 or 2. These include a number of species found only on forest reserves or particular protected satellite islands (Mona and Desecheo). All these species have very limited habitat and none exceed 2 percent of the island.

Forty-seven species are listed as either federally threatened or endangered or given partial status, or are locally listed by the DNER as vulnerable, endangered, critically endangered, or data deficient. The extent of habitat for 70 percent of these species is typically below 5 percent of the island's total area. Eighty-three percent of the species have a habitat extent below 20 percent of the island's total area. *Eleutherodactylus cooki*, the guajón or rock coqui, is the least protected, with no protected habitat. Ten species have less than 10 percent of their habitat protected and 18 species have less than 20 percent of their habitat protected. Five species are found only in reserves with 100 percent of their current distribution protected. Distributions for these species could be expanded outside reserves if suitable habitat is protected or restored and species reintroductions are encouraged.

Conclusions

Puerto Rico is at a crossroads in terms of land use, because much of what was formerly agricultural land is now experiencing more intense, and possibly irreversible, urban development. The current reserve system is well located and protects a number of important habitats and species. However, this system needs to be expanded from 7.6 percent to at least 15 percent of the island's area to be more in line with internationally accepted conservation goals. Our abandoned agricultural land is often a matrix of forested and open green space that serves as habitat for a number of species and buffers older forests, wetlands, riparian areas, and our current reserves. These lands have excellent potential for restoration. Possible restoration plans could include: expanded reserves in the coastal plain, particularly coastal hills and the matrix of wetland and upland vegetation; better regulation of development in the periphery of existing reserves to maintain the integrity of hydrologic systems in wetlands; protection of viable corridors and buffer zones to connect the upland and coastal reserves; development of small and intermediate-sized parks and open space within urban areas that serve as habitat as well as recreational and educational resources for communities; protection of unique habitats such as mountain valleys that shelter the Guajón, *Eleutherodactylus cooki* and the freshwater nonforested wetlands that shelter the Coqui Llanero, *Eleutherodactylus juanariveroii*; and restoration of formerly extensive habitats such as the freshwater swamps or riparian forests of *Pterocarpus officionalis* and the moist lowland Ausubo (*Manilkara bidentata*) forests.

Acknowledgments

This research has been supported by the U.S. Geological Survey Biological Resources Discipline National Gap Program cooperative agreement No. 01HQPG0031 and the U.S. Department of Agriculture Forest Service International Institute of Tropical Forestry (IITF) GIS and Remote Sensing Laboratory. All research at IITF is done in collaboration with the University of Puerto Rico.

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