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# Gap analysis of neotropical dry forests in protected areas using geographical information systems and global datasets

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**Abstract:** A gap analysis was carried out to assess the percentage of neotropical dry forests in protected areas. Antillean and northern South American dry forests were assessed as a subset to assess the conservation importance of Trinidad and Tobago dry forests. The conservation status of dry forests in the neotropics was found to be very poor with over 80% of dry forest ecoregions in the critical/endangered category, indicating they will not persist if current trends in clearing and degradation continue. The gap analysis indicated approximately 1.9 % of the potential dry forest ecoregions were in protected areas of IUCN categories I-III. A similar percentage of dry forest ecoregions was protected in the Lesser Antilles and northern South America, although some dry forest habitat is likely to be protected as part of other seasonal tropical ecoregions such as xeric shrublands.

**Resumen:** Se realizó un Análisis de Huecos ("Gap Analysis") para evaluar el porcentaje de bosques secos neotropicales ubicados en áreas protegidas. Los bosques secos de las Antillas y el norte de Sudamérica fueron evaluados como un subconjunto, con el fin de valorar la importancia de la conservación de los bosques secos de Trinidad y Tobago. El estatus de conservación de los bosques secos del Neotrópico resultó ser muy pobre, con más de 80% de las ecoregiones de bosque seco ubicadas en la categoría crítica/amenazada, indicando que éstas no persistirán si continúan las tendencias actuales de aclareo y degradación de los bosques. El Análisis de Huecos indicó que aproximadamente 1.9% de las regiones potenciales de bosque seco están en áreas protegidas de las categorías I-III de la IUCN. Un porcentaje similar de ecoregiones de bosque seco están protegidas en las Antillas Menores y el norte de Sudamérica, aunque es probable que algunos hábitats de bosque seco estén protegidos como parte de otras regiones tropicales estacionales, tales como las de los matorrales xerófilos.

**Resumo:** A análise de clareiras foi efectuada para avaliar a percentagem de florestas secas neotropicais em áreas protegidas. Florestas secas das Antilhas e da América do Sul foram avaliadas como um subconjunto para avaliar a importância da conservação das florestas secas na Trindade e Tobago. Encontrou-se que o estado de conservação das florestas secas neotropicais era muito pobre com cerca de 80% das ecoregiões de floresta seca na categoria de ameaçadas criticamente, indicando que elas não persistirão se a actual tendência de abate e degradação continuarem. A análise de clareiras indicou que aproximadamente 1,9% das ecoregiões de floresta seca se situavam em áreas protegidas nas categorias I-III da classificação do IUCN. Uma percentagem similar de ecoregiões de floresta seca encontra-se protegida nas Pequenas Antilhas e no norte da América do Sul embora algum habitat florestal seco esteja provavelmente protegido como parte de outras ecoregiões estacionais tropicais tal como nas arbustivas xerófilas.

**Key words:** Biogeography, conservation status, dry forest biome, ecoregions, Lesser Antilles, neotropics, protected area, Tobago, Trinidad, Venezuela.

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## Introduction

In order to understand the conservation status of tropical dry forests, the extent and distribution of the ecosystem type needs to be understood. The potential or pre-Columbian distribution of tropical dry forests is a matter for some debate (Fajardo *et al*. 2005). Seasonal ecosystems such as savannas, deciduous and evergreen dry forest and xeric shrublands differ widely in structure and physiognomy and yet occupy the same or similar biophysical conditions (Gentry 1995; Sarmiento 1972). The TROPI-DRY network of tropical dry forest researchers has defined tropical forests as occurring in areas where mean annual temperature is $\geq$ 25°C, average annual precipitation is between 700 and 2000 mm, and there are at least 3 months of the year receiving less than 100 mm (Sánchez-Azofeifa *et al*. 2005). The reasons for the presence of dry forests, rather than another seasonal ecosystem, at a particular location is complex and case specific; the main drivers are edaphic factors, current land use practices, and historical stochastic events such as droughts and fires or clearing that create meta-stable vegetation communities (Kellman & Tackerberry 1997; Sarmiento 1972). Currently, efforts are underway to map the biophysical factors that favour tropical dry forests on a continental scale in an attempt to represent the potential or pre-Columbian distribution of tropical dry forests (Fajardo *et al*. 2005; Sánchez-Azofeifa *et al*. 2005). Until this is done we can use one of several datasets for dry forest ecosystems (or ecoregions) that have been compiled by expert groups for different countries. These have the disadvantage of not being standard across their range in terms of definition of seasonal vegetation type or in terms of scale of application and thus not verifiable in quantitative terms (Janzen 1988; Olson *et al*. 2001; Quesada & Stoner 2004). However, it is important to carry out this analysis even with such qualitatively derived datasets given the current rate of dry forest ecosystem loss and the need for figures that can be used by decision makers for conservation decisions (Fajardo *et al*. 2005; Sánchez-Azofeifa *et al*. 2005). Gap Analysis is an important conservation tool used to prioritize conservation efforts such as establishment of protected areas (Hunter *et al*. 2003; Jennings 2000). It has been used for conservation units from species to biome scale (Hunter *et al*. 2003; Hoekstra *et al*. 2005). Hoekstra *et al*. (2005) assessed the status of biomes on a global scale using WWF ecoregions classification (Olsen *et al*. 2001), the 2004 World Database on Protected Areas (WDPA Consortium 2005) and Global Land Cover 2000 (GLC 2000) (European Commission Joint Research Centre, Institute for Environment and Sustainability (ECJRC 2002). They found that tropical dry forests were the third most critically endangered biome globally with 48.5 % of the biome cleared and only 7.6 % in protected areas. This study also used datasets derived from Olson *et al*. (2001) and WDPA Consortium (2005).

The specific objective of this study was to assess the floral conservation importance of the dry forests of Trinidad and Tobago at hemispherical and regional scales by conducting a Gap Analysis to determine the percentage of neotropical dry forests ecoregions in protected areas using the comprehensive World Wildlife Fund for Nature (WWF) ecoregion classification (Olson *et al*. 2001) and UNEP-WCMC & IUCN's World Database on Protected Areas (WDPA Consortium 2005).

## Methodology

The conservation status of neotropical dry forests and their protected area status was established by estimating the percentage in protected areas of the biome (Tropical Dry Broadleaf Forest as defined by Olson *et al*. 2001) along with two other biomes that were known to also contain Dry Forest elements at least in northern South America (Bonaccorso 2001; Fajardo *et al*. 2005; Huber 1997); Tropical Grasslands, Savannas and Shrublands; and Deserts and Xeric Shrublands. Tropical Moist Broadleaf Forests were also included in the analysis for comparison (Olson *et al*. 2001; World Wide Fund for Nature 2005). The protected area information was accessed from the 2005 World Protected Areas Database (World Database on Protected Areas Consortium 2005). Analysis of the two datasets was carried out in ArcView 3.2. The two datasets were first clipped to reduce their coverage to the neotropics (between 23.3°N and S Latitude and between 30° and 120° West

Longitude). The total area of Dry Broadleaf Forest, Tropical Grasslands, Savannas and Shrublands, Tropical Moist Broadleaf Forests (included for comparison) and Deserts and Xeric Shrublands Biomes were estimated using the resulting ecoregion theme with the areas of the polygons converted to square kilometers using the X-Tools Extension for ArcView with a Lambert Equal Area azimithul (equatorial) projection (DeLaune 2003). The area of the above biomes was also estimated

**Table 1.** Areas of Neotropical Biomes and their conservation status as defined by WWF (Olsen *et al.* 2001). Conservation status is based on a 30 year prediction of future conservation status given current conservation status and trajectories (GBL_STAT field in the WWF Ecoregions GIS).

| Neotropics | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Biome | Total Number of Ecoregions | Total Area of Biome (km²) | Percentage of Biome Critical/Endangered | | Percentage of Biome Vulnerable | | Percentage of Biome Relatively Stable/Intact | | Percentage of Biome in Protected Areas | |
| | | | By Ecoregion # | By Area | By Ecoregion # | By Area | By Ecoregion # | By Area | IUCN Cat. I-VI | IUCN Cat. I-III |
| Tropical Moist Broadleaf Forests | 78 | 8,638,483.7 | 44.9 | 23.6 | 33.3 | 39.8 | 21.8 | 36.5 | 10.1 | 5.8 |
| Tropical Dry Broadleaf Forests | 30 | 1,037,410.2 | 90.0 | 82.1 | 10.0 | 17.9 | 0.0 | 0.0 | 4.3 | 1.9 |
| Tropical Grasslands, Savannas & Shrublands | 8 | 2,888,235.9 | 25.0 | 4.4 | 62.5 | 94.7 | 12.5 | 0.9 | 4.4 | 3.9 |
| Deserts & Xeric Shrublands | 17 | 1,301,362.0 | 52.9 | 20.1 | 41.2 | 79.9 | 5.9 | 0.0 | 3.0 | 1.4 |
| Northern South America and the Lesser Antilles* | | | | | | | | | | |
| Tropical Moist Broadleaf Forests | 30 | 1,337,588.8 | 26.7 | 20.3 | 36.7 | 38.9 | 36.7 | 40.8 | 26.8 | 13.3 |
| Tropical Dry Broadleaf Forests | 9 | 170,851.1 | 88.9 | 59.9 | 11.1 | 40.1 | 0.0 | 0.0 | 9.4 | 1.5 |
| Tropical Grasslands, Savannas & Shrublands | 2 | 390,358.0 | 0.0 | 0.0 | 100.0 | 100.0 | 0.0 | 0.0 | 14.3 | 10.4 |
| Deserts & Xeric Shrublands | 5 | 122,600.3 | 80.0 | 98.2 | 20.0 | 1.8 | 0.0 | 0.0 | 10.6 | 3.0 |

* northern south America = Columbia, Trinidad & Tobago, Guyana, French Guiana, Suriname and Venezuela; Lesser Antilles = Anguilla, Antiga & Barbuda, Aruba, Barbados, Dominica, Grenada, Guadelope, Martinque, Montserrat, Netherlands Antilles, St. Kitts & Nevis, St. Lucia, and St. Vincent & the Grenadines.

for northern South America (Columbia, Venezuela the Guianas and Trinidad & Tobago) combined with the Lesser Antilles (Anguilla, Antigua & Barbuda, Aruba, Barbados, Dominica, Grenada, Guadelope, Martinique, Montserrat, Netherlands Antilles, St. Kitts & Nevis, St. Lucia, and St. Vincent & the Grenadines) as these areas had the closest floristic affinity to the Little Tobago Dry Forests (Oatham & Boodram in prep). To get an idea of the overall conservation status of each biome in the neotropics, the percentage of each biome assigned to one of three levels of conservation status (Critical/Endangered; Vulnerable; or Relatively Stable/Intact) as designated by Olson *et al.* (2001) was calculated in two ways: by the number of ecoregions and by area.

The neotropical ecoregions layer and the neotropical Protected Areas layer were intersected to determine the area of each of the biomes of interest in a protected area of IUCN category I-VI or I to III (protected areas established specifically to conserve biodiversity and that are managed with a minimum of human intervention) (IUCN 1994). Only protected areas represented by polygons were included in this analysis. Polygon areas were again converted to square kilometers using the X-Tools extension (DeLaune 2003).

## Results

The neotropical seasonal biomes considered in this study (Tropical Dry Forest, Tropical Grasslands, Savannas and Shrublands, and Deserts and Xeric Shrublands as defined by Olson *et al.* (2001)) covered an area of 5,227,008 km$^2$ of which dry forest covered 1,037,410 km$^2$. These figures were the maximum potential extent of the biomes, but with clearing and degradation the area covered by intact ecosystems is far lower. No attempt was made to quantify this lower figure and instead the percentage of each biome classified into the three WWF conservation status categories (Olsen *et al.* 2001) was calculated by ecoregion number and by area (Table 1). The percentage of each biome in protected areas of IUCN categories I-VI and categories I-III was also calculated (Table 1). By area, the Tropical Dry Broadleaf Forest biome has 82% and 60% of ecoregions in the Critical/Endangered category in the neotropics and in northern South America (Columbia, Venezuela and the Guianas) and the Lesser Antilles, respectively (Table 1). The Tropical Dry Forest biome has no ecoregions that are Relatively Stable/Intact in the neotropics. This compares very unfavorably with the other biomes analyzed (Table 1). The percentage of Tropical Dry Forest biome represented in protected areas with an IUCN classification of I-VI is 4.3 % in the neotropics, falling to 1.9 % in Category I-III protected areas. In northern South America and the Lesser Antilles, 9.4 % of the Tropical Dry Forest biome is in Category I-VI protected areas, falling to 1.5 % in the Category I-III protected areas (Table 1).

## Discussion

The analysis of conservation status of Tropical Dry Broadleaf Forest carried out in this study supports the statements of Sánchez-Azofeifa *et al.* (2005), Pennington *et al.* (2000), Dinerstein *et al.*. (1995), Murphy & Lugo (1995), Janzen (1986), Maass (1995) & Beard (1949). The Tropical Dry Broadleaf Forest biome is one of the most threatened in the neotropics. If current trends continue over 80 % of Dry Forest ecoregions that are classified as Critical/Endangered today by Olson *et al.* (2001), will be lost in the neotropics and over 89 % in N. South America and the Lesser Antilles. Specifically, the Lesser Antillean Dry Forests Ecoregion is classified as Critical/ Endangered by Olson *et al.* (2001). The very precarious state of the Tropical Dry Broadleaf biome is alleviated somewhat by the occurrence of Dry Forests in other seasonal biomes of the neotropics such as Deserts and Xeric Shrublands and Tropical Grasslands, Savannas and Shrublands. The Araya and Paria Xeric Shrub ecoregion on the Paria Peninsula opposite the Northern Range in Trinidad is a good example (see Fajardo *et al.* 2005). The wetter part of the Araya and Paria Xeric shrub ecoregion where it borders the Cordillera la Costa Montane Forests ecoregion as described by Huber (1997) and Bonaccorso (2001) are probably the Venezuelan deciduous forests as described by Beard (1944) (see also Fajardo *et al.* 2005). However, these biomes, particularly the Desert and Xeric Shrubland biome, are also conservationally challenged particularly in northern South America (Bonaccorso 2001; Fajardo *et al.* 2005) (Table 2).

**Table 2.** Protected areas in N. South America* and the Lesser Antilles* that contain an area of Tropical Dry Broadleaf Forest, Tropical Grasslands, Savanna and Shrublands, or Desert and Xeric Shrublands (Olson *et al.* 2001). Data from the 2005 World Database on Protected Areas (WDPA Consortium 2005) and Olson *et al.* (2001).

| Biome | Country | Name of Protected Area | Designation of Protected Area | IUCN Categy | Total Area of Protected Area ($km^2$)** | Area of Biome in Protected Area ($km^2$) |
|---|---|---|---|---|---|---|
| Tropical Dry Broadleaf Forest | | | | | | |
| | Antigua and Barbuda | Nelson's Dockyard | National Park | II | 58.3 | 8.4 |
| | Colombia | Ciénaga Grande de Santa Marta | Fauna and Flora Sanctuary | Ia | 270.9 | 47.0 |
| | | Cordillera de los Picachos | Natural National Park | II | 2,750.5 | 447.6 |
| | | Isla de Salamanca | Natural National Park | II | 589.9 | 5.2 |
| | | Sierra de la Macarena | Natural National Park | II | 6,203.2 | 405.3 |
| | | Sierra Nevada de Santa Marta | Natural National Park | II | 4,164.2 | 656.0 |
| | | Sumapaz | Natural National Park | II | 2,037.5 | 15.3 |
| | | Tinigua | Natural National Park | II | 2,252.9 | 330.6 |
| | Venezuela | Cerro Saroche | National Park | II | 691.6 | 22.6 |
| | | Cueva de la Quebrada del Toro | National Park | II | 71.9 | 71.9 |
| | | El Tamá | National Park | II | 1,602.8 | 108.6 |
| | | Médanos de Coro | National Park | II | 1,112.5 | 235.2 |
| | | Sierra de San Luis | National Park | II | 203.8 | 203.8 |
| | | | | Total of Biome in Protected Areas: | | 2,557.4 |
| Tropical Grasslands, Savannas and Shrublands | | | | | | |
| | Colombia | El Tuparro | Natural National Park | II | 5,519.1 | 5,519.1 |
| | Venezuela | Aguaro-Guariquito | National Park | II | 5,861.0 | 5,861.0 |
| | | Canaima | National Park | II | 30,453.8 | 11,7337 |
| | | Cinaruco-Capanaparo | National Park | II | 6,719.6 | 6,719.6 |
| | | Formaciones de Tepuyes | Natural Monument | III | 51,237.0 | 12,3723 |
| | | Yacambú | National Park | II | 173.7 | 10.5 |
| | | | | Total of Biome in Protected Areas: | | 42,2162 |
| Deserts and Xeric Shrublands | | | | | | |
| | Antigua and Barbuda | Nelson's Dockyard | National Park | II | 58.3 | 9.2 |
| | Colombia | Isla de Salamanca | Natural National Park | II | 589.9 | 0.3 |
| | | Los Flamencos | Fauna and Flora Sanctuary | Ia | 79.0 | 78.0 |
| | | Macuira | Natural National Park | II | 243.2 | 243.2 |
| | | Sierra Nevada de Santa Marta | Natural National Park | II | 4,164.2 | 21.3 |
| | | Tayrona | Natural National Park | II | 212.2 | 41.1 |
| | Netherlands Antilles | Christoffel (Curacao) | National Park | II | 23.2 | 16.2 |
| | | Saba | Marine Park | II | 5.3 | 1.3 |
| | Venezuela | Cerro El Copey | National Park | II | 32.8 | 32.8 |
| | | Cerro Platillón | Natural Monument | III | 64.9 | 64.9 |
| | | Cerro Santa Ana | Natural Monument | III | 34.1 | 34.1 |
| | | Cerro Saroche | National Park | II | 691.6 | 669.0 |
| | | Cerros Matasiete y Guayamurí | Natural Monument | III | 12.8 | 12.7 |
| | | Dinira | National Park | II | 290.1 | 23.7 |
| | | El Avila | National Park | II | 705.3 | 87.0 |
| | | El Guácharo | National Park | II | 535.3 | 111.8 |

Continued.

**Table 2.** Continued.

| | | | | | |
|---|---|---|---|---|---|
| | Guatopo | National Park | II | 988.9 | 352.5 |
| | Henri Pittier | National Park | II | 880.4 | 287.2 |
| | Laguna de la Restinga | National Park | II | 30.9 | 27.1 |
| | Laguna de las Marites | Natural Monument | III | 20.0 | 0.3 |
| | Laguna de Tacarigua | National Park | II | 313.2 | 84.7 |
| | Loma de León | Natural Monument | III | 28.5 | 15.6 |
| | María Lionza | Natural Monument | III | 270.4 | 270.4 |
| | Mochima | National Park | II | 832.1 | 287.7 |
| | Morros de San Juan (Arístides Rojas) | Natural Monument | III | 35.3 | 35.3 |
| | Médanos de Coro | National Park | II | 1,112.5 | 346.1 |
| | Península de Paria | National Park | II | 588.0 | 145.3 |
| | San Esteban | National Park | II | 318.6 | 177.1 |
| | Terepaima | National Park | II | 214.9 | 59.6 |
| | Turuépano | National Park | II | 677.2 | 49.3 |
| | Yurubí | National Park | II | 382.0 | 137.3 |
| | | | | Total of Biome in Protected Areas: | 3,722.2 |

* northern South America = Columbia, Trinidad & Tobago and Venezuela; Lesser Antilles = Anguilla, Antigua & Barbuda, Aruba, Barbados, Dominica, Grenada, Guadelope, Martinque, Montserrat, Netherlands Antilles, St. Kitts & Nevis, St. Lucia, and St. Vincent & the Grenadines.

** Area on GIS of the 2005 World Database on Protected Areas (WDPA Consortium 2005)

GAP Analysis shows the percentage of the Tropical Dry Broadleaf Forest biome in protected areas is very low in the neotropics, particularly in the IUCN Categories I-III. The areas protected are far less than the minimum of 10 % of each biome protected adopted as a conservation goal of The Fourth World Congress on National Parks and Protected Areas held in Caracas, Venezuela in 1992 (Brooks *et al.* 2004). Protected areas that include dry forest ecoregions in northern South America and the Lesser Antilles to which the dry forests of Trinidad and Tobago have the closest floristic affinity (including the Xeric Shrublands/Montane Forest transition on the Paria Penninsula) are generally small and isolated and are a small proportion of the potential dry forest ecoregions (Table 2). Outside of these protected areas, the Dry Forest is either degraded or converted to other uses (Armstrong 2001a,b,c; Bonaccorso 2001; Farjado *et al.* 2005; Huber 1997; Locklin 2001). This is the case in Venezuela, NW Trinidad, SW Tobago and the Lesser Antilles (Farjado *et al.* 2005; Olson *et al.* 2001). There appear to be no protected areas for dry forests in the Lesser Antilles whose countries have tended to focus conservation efforts on the interior montane forests. The results of this analysis echo that of Hoekstra *et al.* (2005). It appears that the conservation state of tropical dry forest in the neotropics and in northern South America and the Lesser Antilles is worse than the average global state for tropical dry forest (Hoeskstra *et al.* 2005). This analysis clearly signals the need for far more attention to be paid to the conservation of tropical dry forest in northern South America and the Lesser Antilles and in the neotropics in general. In this context, Little Tobago Island and other dry forests in the Trinidad and Tobago such as the Islands of the Bocas and the Southern Watershed Wildlife Sanctuary, are of very high conservation importance and should be prioritized in national or regional conservation planning.

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