Research Notes

Deforestation and Plant Diversity of Madagascar's Littoral Forests

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Abstract: *Few studies have attempted to quantify the reduction or document the floristic composition of forests in Madagascar. Thus, we focused specifically on deforestation and plant diversity in Madagascar's eastern littoral community. We used a data set of approximately 13,500 specimen records compiled from both historical and contemporary collections resulting from recent intensive inventory efforts to enumerate total plant species richness and to analyze the degree of endemism within littoral forests. Change in littoral forest cover from original to current extent was estimated using geographical information systems tools, remote sensing data (satellite imagery and low-elevation digital photography), and environmental data layers. Of the original littoral forest only 10.3% remains in the form of small forest parcels, and only 1.5% of these remaining fragments are included within the existing protected-areas network. Additionally, approximately 13% of Madagascar's total native flora has been recorded from these forests that originally occupied <1% of its total land surface, and over 25% of the 1535 plant species known from littoral forests are endemic to this community. Given the ongoing pressure from human settlement along Madagascar's eastern coast, protection of the remaining forest fragments is critical for their survival. Fifteen of the largest intact littoral forest fragments we identified, collectively representing 41.5% of remaining littoral forest, are among priority sites recommended to the government of Madagascar for plant conservation and incorporation into the protected-areas network.*

Keywords: endemism, forest change, GIS, plant conservation, remote sensing

Deforestación y la Diversidad de Plantas en los Bosques Litorales de Madagascar

Resumen: *Pocos estudios han intentado cuantificar la reducción o documentar la composición florística de los bosques en Madagascar. Por lo tanto, nos concentramos específicamente en la deforestación y la diversidad de plantas en la comunidad litoral del este de Madagascar. Utilizamos un conjunto de datos con aproximadamente 13,500 registros de especimenes compilados de colecciones históricas y contemporáneas resultantes de esfuerzos intensivos de inventariado para enumerar la riqueza total de especies de plantas y para analizar el grado de endemismo en los bosques litorales. El cambio en la cobertura de los bosques litorales desde la original a la actual fue estimado mediante herramientas de sistemas de información geográfica, datos de sensores remotos (imágenes de satélite y fotografía digital de baja altura) y capas de datos ambientales. Del bosque litoral original, solo queda 10.3% en forma de pequeñas parcelas de bosque, y solo 1.5% de esto fragmentos remanentes están incluidos en la red de áreas protegidas. Adicionalmente, se ha registrado aproximadamente 13% de la flora nativa total de Madagascar en estos bosques que originalmente ocuparon <1% de la superficie total de la isla, y más de 25% de las 1535 especies de plantas conocidas de los bosques de litoral son endémicas*

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a esta comunidad. Dada la presión continua de los asentamientos humanos a lo largo de la costa oriental de Madagascar, la protección de los fragmentos de bosque remanentes es crítica para su supervivencia. Quince de los fragmentos más grandes de bosque intacto que identificamos, que colectivamente representan 41.5% del bosque litoral remanente, están entre los sitios prioritarios recomendados al gobierno de Madagascar para la conservación de plantas y si incorporación a la red de áreas protegidas.

Palabras Clave: cambios forestales, conservación de plantas, endemismo, sensores remotos, SIG

Introduction

Madagascar harbors an exceptional biota (Goodman & Benstead 2005). High overall diversity, levels of endemism, and rates of deforestation amply justify its status as one of the world's hottest hotspots for biodiversity conservation (Myers et al. 2000; Ganzhorn et al. 2001; Mittermeier et al. 2004). Most of that biodiversity occurs in humid and subhumid, evergreen forests that occupy the windward, eastern portion of the island, with an extension into the Sambirano region, west of Vohemar. Within these moist forests, the narrow coastal strip of forest that occurs on sand constitutes a distinct community referred to as littoral forest. (e.g., Rabevohitra et al. 1998; de Gouvenain & Silander 2000; Cadotte et al. 2002). Although some littoral forest sites figured prominently in the earliest botanical exploration of Madagascar during the eighteenth century, until the 1980s these specialized forests were one of the island's more poorly documented vegetation types. Intensive botanical inventory efforts focusing on littoral forests in the Fort Dauphin area in southeastern Madagascar were conducted in the late 1980s as part of an environmental impact assessment for a planned mining operation (Vincelette et al. 2003). The results demonstrated the exceptional floristic diversity of this ecosystem, prompting expanded inventory work during the past decade that has generated approximately 9000 collections spanning the entire latitudinal range of littoral forest and shedding new light on its biological and conservation importance.

Littoral forest is thought to have once formed a continuous 1600-km band along most of Madagascar's eastern coast (Green & Sussman 1990; de Gouvenain & Silander 2004), but it now exists only as isolated, remnant fragments, all of which are subject to continuing pressure from local inhabitants in coastal villages for fuel wood and construction materials. Recent deforestation estimates of Madagascar's moist forests as a whole show dramatic rates of loss (Green & Sussman 1990; Mittermeier et al. 2004), but no researchers have focused specifically on the extent of littoral forests and their contribution to Madagascar's overall plant diversity. We estimated the loss of littoral forest in Madagascar from its probable original (precolonization) extent to its current extent. We used geographical information systems (GIS) with a suite of data layers including elevation, geology, and forest cover derived from Landsat images and aerial photographs to highlight the extraordinary plant diversity and endemism within these highly threatened forests.

Methods

Study Site

Our study area included littoral forest in the humid and subhumid zones as defined by Cornet (1974), extending from Lac Sahaka forest in the north (13° 04′S, 49° 54′E) to the Fort Dauphin region in the south (25° 04′S, 46° 51′E). Although the Lac Sahaka forest falls just within the dry bioclimatic zone, we included it in the analysis because its floristic composition is more similar to that of littoral forests in the humid and subhumid zones just to the south than to that of drier coastal forest on sand farther north.

Defining Original Forest Extent

We used GIS applications to estimate the original (precolonization) extent of humid and subhumid littoral forest. Current littoral forest occurs on low-elevation sandy soil within a few kilometers of the shoreline. Thus, we selected all areas at or below 25 m in elevation from the Shuttle Mission Topography Radar (SRTM) 90-m digital elevation model (USGS 2004). We converted this elevation data to a 30-m cell size with the Resample tool in ArcGIS 9.0 ArcToolbox (ESRI, Redlands, California) to be consistent with the cell size of the data layers derived from the Landsat images used in our study.

All areas of mangrove and water were removed from the low-elevation grid with a forest-change map derived from Landsat images (G. J. Harper, M. K. Steininger, C. J. Tucker, D. Juhn, and F. Hawkins, unpublished data).

As a third filter, we refined the resulting grid in relation to a geology layer (Besairie 1964; Du Puy & Moat 1996), retaining only those areas that intersected with unconsolidated sand, sandstone, and alluvial deposits. Aerial photography was carried out during a flyover of the entire eastern coast in May 2003, resulting in approximately 2000 digital images with 10-m resolution. Photographs were taken with a digital camera attached to the underside of the aircraft flying at 3000 m. Images were taken automatically at 15-second intervals via remote control (Nikon Capture 2 software (Nikon, Melville, New York).

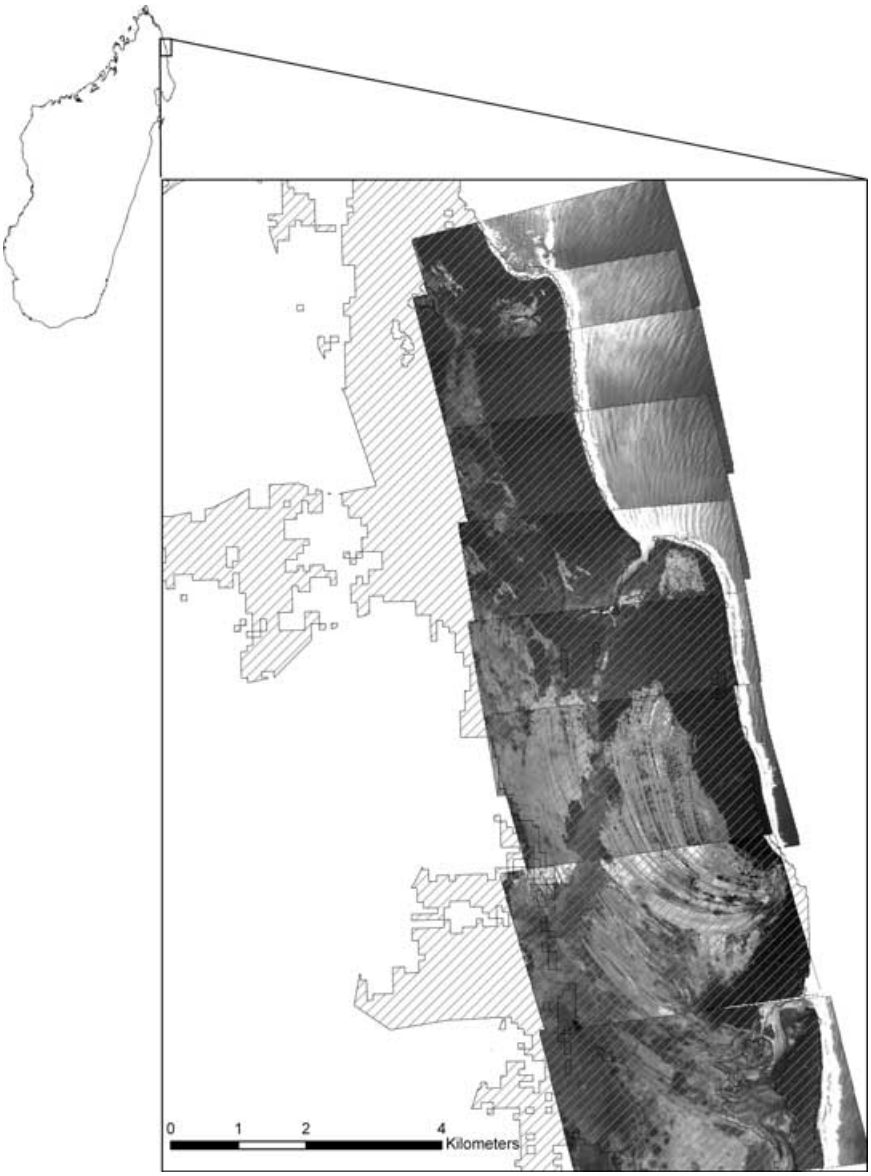

Figure 1. A mosaic of digital aerial photographs of the Ambondrobe Forest along the eastern coast of Madagascar. Hatched region shows estimated original (precolonization) littoral forest cover.

A GPS (Magellan, Santa Clara, California) synchronized to the camera imprinted a georeference stamp (latitude and longitude) at the center of each photograph. Digital images were georectified with the Image Analyst extension in ArcView 3.2 and Level 1G Landsat images from 1999 to 2003 (geometric accuracy within 250 m for low-relief areas at sea level [USGS 2004]). Each image covered an area of about 4 km inland from the coastline. Intensive field surveys augmented our interpretation of remote sensing data.

We used Image Analyst to form a photographic mosaic from which polygons of each site were created with the "seed tool." We calculated area for each forest polygon with the calculate area tool in ArcToolbox. For areas of littoral forest believed to extend farther inland than 4 km, we used data from Harper et al. (2006; remaining forest as of 2000) to estimate forest cover. Finally, we combined our current littoral forest cover layer with a protected-areas layer to determine the percentage of remaining littoral forest contained within the protected-areas network. Georectified jpeg images and a shapefile (GIS layer) of extant littoral forest are available from http://www.mobot.org/MOBOT/research/littoral/supplementary_material.shtml.

Specimen Data

A list of plant species occurring in humid and subhumid littoral forest was generated from over 13,500 georeferenced specimen records in the W^3 TROPICOS database (Missouri Botanical Garden 2005). To estimate the degree of endemism within littoral forests, we compared the resulting floristic inventory with a list of over 9,000 plant species based on approximately 79,400 georeferenced specimen records from throughout Madagascar (Missouri Botanical Garden 2005).

Results

Percent Forest Cover Loss

Prior to human colonization, humid and subhumid littoral forest covered approximately 465,100 ha, or 0.8% of the total land surface of Madagascar, of which only about 47,900 ha remain today, indicating an 89.7% loss of original cover (Fig. 1). Of the remaining littoral forest, only 1.5% (695 ha) is within the protected-areas network. Green and Sussman (1990) estimate that by 1950, 67% of Madagascar's original eastern moist forests remained, whereas by 1985 only 34% remained. They stated that areas on less steep slopes were most vulnerable to further conversion. Similarly, results of studies in three littoral forest fragments in southern Madagascar showed almost half of their cover was removed between 1950 and 1995 (Dawson et al. 2000; Ingram et al. 2005). Our results indicate that littoral forest has been reduced at a rate considerably higher than that of eastern moist forests as a whole. We used our data to identify the largest fragments of intact littoral forest (Table 1).

Representation of Malagasy Flora and Endemism

Collection records to date document 1535 plant species from humid and subhumid littoral forest, a remarkable 17% of the approximately 9000 species for all of Madagascar represented in the Missouri Botanical Garden's W^3 TROPICOS database. The total native vascular flora of Madagascar is estimated to be 12,000 species based on approximately 250,000 collections in herbaria worldwide (Schatz et al. 1996), which suggests that littoral forest contains 13% of Madagascar's total plant diversity in <1% of its total land surface. Our data also indicate that at least 400 plant species are endemic to littoral forest, thus representing >25% of all littoral species and approximately 3.3% of Madagascar's total flora.

Table 1. Remaining littoral forest fragments that currently lack protection and have been recommended for incorporation into Madagascar's protected-areas network.

Name	*Area (ha)*	*Location (S latitude E longitude)*
Lac Sahaka	2200	13° 04′ 49° 54′
Ambondrobe	2650	13° 46′ 50° 06′
Pointe à Larrée	1475	16° 47′ 49° 43′
Île Sainte Marie	1190	16° 49′ 49° 57′
Tampolo	740	17° 16′ 49° 25′
Mahatsara	85	17° 37′ 49° 29′
Antetezana	485	17° 49′ 49° 28′
Vohibola	2150	18° 28′ 49° 17′
Ambila-Lemaitso	1175	18° 45′ 49° 10′
Nankinana	1820	20° 20′ 48° 36′
Ambahy	1720	20° 41′ 48° 30′
Mahabo	1240	23° 11′ 47° 43′
Sainte Luce	1580	24° 48′ 47° 08′
Mandena	535	24° 57′ 46° 59′
Petriky	835	25° 04′ 46° 51′
Total	19,880	

Discussion

With nearly 90% of the original littoral forest already lost, there is an urgent need to protect the remaining parcels to avoid the extinction of hundreds of endemic species. In addition to sheltering a large number of threatened plant and animal species (Dumetz 1999; Schatz 2000; Watson et al. 2005), littoral forests serve as the first line of defense against cyclonic depressions, providing protection for both human inhabitants and the estuarine breeding sites of marine invertebrates (Vasudeva et al. 2003).

The 1.5% of remaining littoral forest encompassed within Madagascar's protected-areas network consists of five small fragments: four that were deliberately included within the recently established Masoala National Park (Kremen et al. 1999) and one that was a badly degraded fragment at Manombo Special Reserve. None of the largest remaining littoral forest fragments is currently afforded protection (Table 1). Nevertheless, at the 2003 World Parks Congress, Madagascar's president, Marc Ravalomanana, charged his government and its nongovernmental organization partners with formulating recommendations for the addition of 4.5 million ha to the protected-areas network. The first set of areas proposed by a governmentally appointed advisory group for this initiative in early 2005 included 15 parcels of littoral forest totaling 19,880 ha, representing 41.5% of remaining littoral forest (Table 1).

Incorporation of these largest remaining parcels in the protected-areas network offers the best hope for long-term persistence of Madagascar's unique littoral forest community, while achieving a disproportionately high degree of biodiversity conservation. Specific recommendations on priority littoral forest sites are an especially critical element in the effort to expand the protected-areas network given their high rate of loss, small remaining area, inadequate representation in this network, and disproportionately high diversity of plant species.

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