Dynamics of Tropical Deforestation Around National Parks: Remote Sensing of Forest Change on the Osa Peninsula of Costa Rica

Authors: Sanchez-Azofeifa, G. Arturo, Rivard, Benoit, Calvo, Julio, and Moorthy, Inian

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G. Arturo Sanchez-Azofeifa, Benoit Rivard, Julio Calvo, and Inian Moorthy

Dynamics of Tropical Deforestation Around National Parks:
Remote Sensing of Forest Change on the Osa Peninsula of Costa Rica

National parks and biological reserves play an important role in counteracting the effects of tropical deforestation in mountainous environments, a leading cause of biodiversity loss worldwide. Unfortunately, information is sparse on the nature, dynamics, and spatial dimension of land use and land cover change processes that contribute to park vulnerability. This article assesses the current state of landscape fragmentation and structure on the Osa Peninsula, Costa Rica, using Landsat Multispectral Scanner and Thematic Mapper satellite scenes between 1979 and 1997. The Osa Peninsula hosts the Corcovado National Park, which contains the only protected region of Tropical Wet forest on the Pacific slopes of Mesoamerica, including a significant number of species that are endemic, threatened, or new to science. The level of isolation of the Corcovado National Park is based on the degree of ecosystem degradation produced by frontal deforestation processes. Our results indicate that the proportion of the Osa Peninsula covered by forest declined from 97% in 1979 to 91% in 1987 and to 89% by 1997. Total forest area declined from 977 km^2 in 1979 to 896 km^2 by 1997. These results pose significant questions regarding the effectiveness of current conservation efforts in this mountain biodiversity-rich area of Mesoamerica.

Keywords: *Costa Rica; tropical deforestation; habitat fragmentation; remote sensing; national parks.*

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Introduction

National parks and biological reserves play an important role in counteracting the effects of tropical deforestation, a leading cause of biodiversity loss worldwide (Guppy 1984; Myers 1993; Bawa and Seidler 1998). However, in many cases, these managed areas are not fully integrated into regional conservation networks. Uncontrolled deforestation and habitat fragmentation beyond the boundaries of the parks contribute to their vulnerability and to the truncation of corridors between protected areas (Soulé and Ternorgh 1999). Conservation advocates tend to seek protection for unique areas that are less disturbed than the surrounding landscapes; this is an important work that must continue. Unfortunately, if the targeted areas are too small or too isolated (or both), they are susceptible to loss of both genetic and species diversity, especially during extreme climatic events or other disturbances (Robinson et al 1992). Most conservation area managers and researchers recognize the need for corridors that link conservation areas into conservation nets. These corridors provide habitat continuation and maximize gene and species movement to protect and preserve biodiversity.

Such efforts, aimed at maintaining healthy ecosystems, are critical for mountainous countries such as Costa Rica, which is considered to be one of the most biologically diverse regions of the world. It is estimated that 5% of all living species (approximately 500,000) are found in this small tropical country, even though it covers only 0.01% of the earth's landmass (INBio 1999). At present, a total of 25% of the national territory has been set aside for national parks and biological reserves (Sanchez-Azofeifa 1996). Outside these areas, however, economic pressures have resulted in a high rate of deforestation and habitat fragmentation (Sanchez-Azofeifa et al 1999). For example, in 1992, Costa Rica's Strategy for Sustainable Development (ECODES) indicated that, if unchanged, the trend toward unsustainable management of the country's forest resources during the last 50 years would deplete all primary forests of commercial timber by 1995 (Quesada-Mateo 1990). This prediction did not materialize, thanks to an aggressive campaign aimed at slowing the country's deforestation rate, but the events surrounding it illustrate the struggle between conservation and development efforts in Costa Rica (Castro-Salazar and Arias-Murillo 1998).

During the last 2 decades, efforts to document regional deforestation rates and habitat fragmentation in Costa Rica have been undertaken by several authors (Castro-Salazar and Arias-Murillo 1998; Sader and Joyce 1988; Sanchez-Azofeifa et al 2001). Regional deforestation studies can help document the extent of the vulnerability of a protected area and support conservation efforts aimed at addressing the issue of the isolation of national parks and biological reserves, as well as the conceptualization and implementation of sustainable development policies constrained by limited funding. A common denominator of these studies has been their nationwide scale and their wide differences with respect to assessments of the extent of forest left in the country. In contrast, few studies have documented deforestation and habitat fragmentation processes at subnational levels (Veldkamp et al 1992; Sanchez-Azofeifa and Quesada-Mateo 1995; Sanchez-Azofeifa et al 1999). Nationwide studies, which are concerned only with aggregate levels of land use and land cover change, cannot provide information on the extent or nature of deforestation beyond the boundaries of national parks, on the growing vulnerability of protected areas, and on the context of these threats to species distribution. Localized information on deforestation trends is important for understanding the interactions between the local human dimension of the land cover change and the temporal changes in the tropical landscape, a concept known in physical and social sciences as "socializing the pixel" (Geoghegan and Pritchard 1995). The present article focuses on the Corcovado National Park and the Osa Peninsula in southern Costa Rica as examples of the growing incidence of landscape fragmentation and isolation of national parks in Costa Rica. The objectives are to assess the current state of forest cover and landscape fragmentation on the Osa Peninsula (Figure 1) and to examine the level of vulnerability of the Corcovado National Park in the context of regional patterns of deforestation. Finally, we illustrate the effect of deforestation on conservation efforts using examples of species that are endemic, threatened, or new to science.

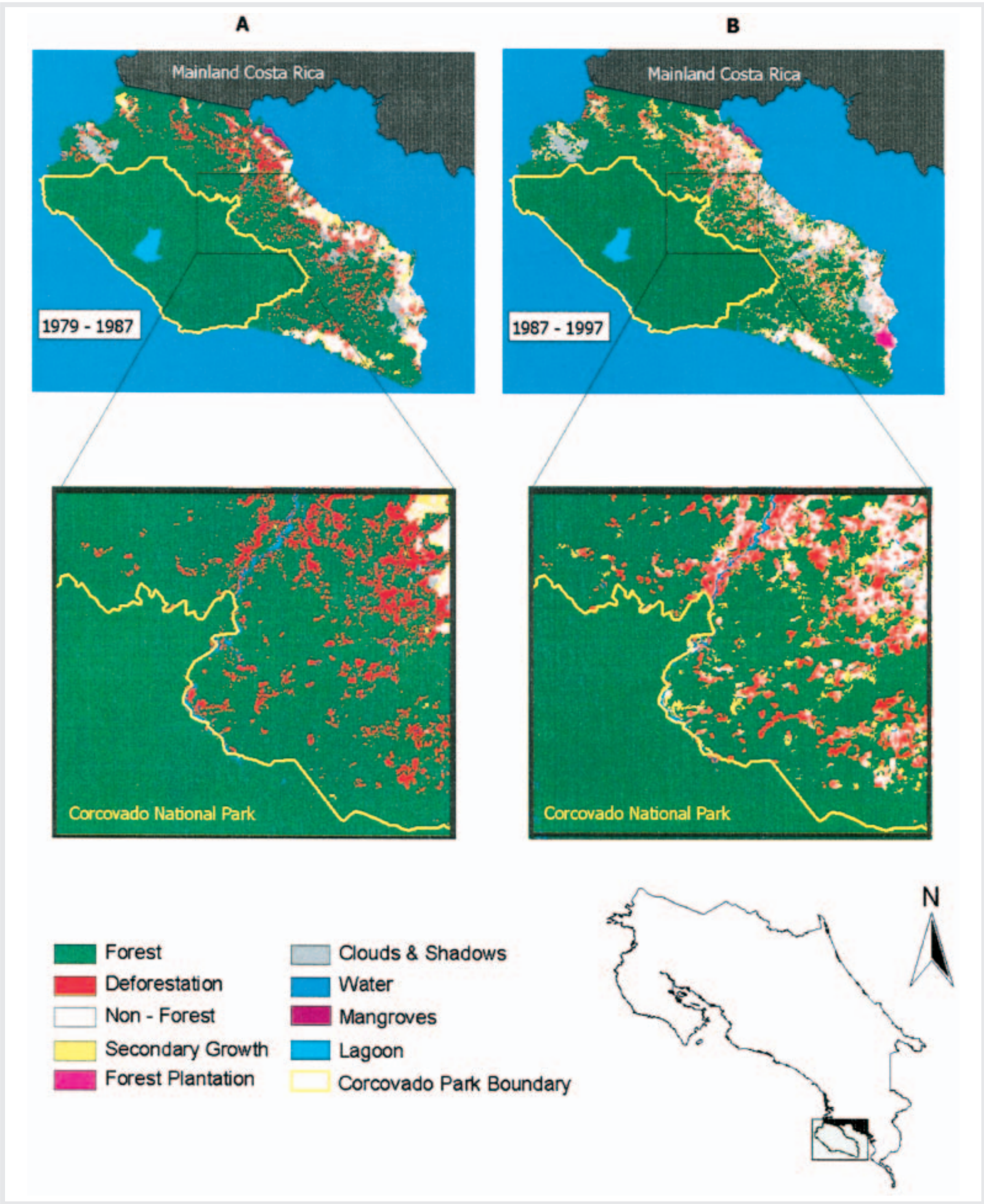

FIGURE 1 Regional deforestation rates for the Osa Peninsula. The satellite data consisted of 3 images, 1 from the Landsat Multispectral Scanner (MSS, 80-m resolution and 4 spectral bands; 22 January 1979) and 2 from the Landsat Thematic Mapper (TM, 28.5-m resolution and 7 spectral bands; 17 January 1987 and 13 March 1997). Red represents forest lost for each study period. Deforestation far from the national park is occurring on isolated forest patches, whereas deforestation close to the park is occurring on mature tropical forest. A: 1979–1987. B: 1987–1997.

Study area

The Osa Peninsula (1093 km^2) is a unique ecosystem on the Pacific slopes of Mesoamerica that consists of Tropical Wet, Premontane Wet, and Tropical Moist forest types, as defined by the Life Zones Classification System of Holdridge (1967). This vegetation classification system takes into consideration elevation, annual biotemperature, precipitation/relative humidity, and evapo-transpiration to characterize tropical, temperate, and boreal ecosystems. The 3 forest types observed in the Osa Peninsula represent the last remaining types of evergreen tropical forest on the Pacific coast of the Mesoamerican Isthmus (Hartshorn 1983). Mean annual precipitation is 5500 mm, distributed between a dry season (December–April) and a wet season (May–November). Mean annual temperature is 27°C. Elevations on the Osa Peninsula range between 200 and 760 m. The average slope is 40%, with significant areas close to 90% and 100%.

The Osa Peninsula, and its fragile ecosystems, comprises a critical region for conservation of biological resources. Approximately one third of the tree species recorded in Costa Rica are found in this region (approximately 700 species), including 55% of the country's endangered tree species (Barrantes et al 1999). Moreover, it has been estimated that the Osa Peninsula may contain 4000–5000 vascular plant, 8000 insect, 375 bird (18 endemic to the region), 124 mammal, 71 reptile, and 46 amphibian species. Of the tree species, 60–70% are currently being harvested, and about 14,000 trees have been selectively logged during the last 2 years (Barrantes et al 1999). The Corcovado National Park, which covers approximately 425 km^2, is the only public conservation area in existence on the Osa Peninsula.

Materials and methods

A temporal analysis of deforestation and forest fragmentation on the Osa Peninsula was conducted using 3 images recorded by the Landsat Multispectral Scanner (MSS) (80-m spatial resolution and 4 spectral bands) and Landsat Thematic Mapper (TM) satellites (28.5-m spatial resolution and 7 spectral bands). MSS data were acquired on 22 January 1979, and TM data were acquired on 17 January 1987 and 13 March 1997. All images corresponded to the dry season. The imagery was orthorectified to a Lambert Conformal Conical projection using a digital elevation model (DEM) produced from 1:50,000 topographic maps (CATIE 2000). Images were atmospherically corrected using ACTOR 2 (produced by Geosystems in 2002). No calibrations for sensor drift or solar angle were performed because the techniques used in this study did not require this level of preprocessing. Several inaccuracies associated with DEM did not allow for an accurate topographic correction of the imagery, and therefore, more advanced corrections were not performed. The lack of topographic, sensor drift correction did not alter the results of this study.

The satellite images were processed individually, using a technique developed by the NASA Pathfinder tropical deforestation project defined as "in-pair processing" (Chomentowsky et al 1994). Each image was classified individually into 5 classes: water, clouds, shade, forest, and nonforest. Forest was defined as having canopy closure greater than 80% (analysis of aerial photography). Additional information regarding the relationship between spectral reflectance and canopy closure can be found in Sanchez-Azofeifa (1996) and Sanchez-Azofeifa et al (2001). Each classification produced an individual map that was transferred from raster to vector format, thereby avoiding problems with sensor resolution. Vector format maps were then used to produce deforestation trend and fragmentation analysis. The nature of the overall classification processes can be found in Sanchez-Azofeifa et al (2001).

A minimum mapping unit of 0.05 km^2 was selected for the final map product. The images were first rectified and classified in raster format and then converted to a vector format for spatial analysis and display (Skole and Tucker 1993). Final forest cover maps for 1979, 1987, and 1997 were used to estimate the extent and rate of deforestation and to quantify forest fragmentation statistics during the periods of 1979–1987 and 1987–1997. The degree of forest degradation was evaluated using an approach developed for tropical regions by Skole and Tucker (1993), namely the implementation of a 1-km buffer zone from forest–nonforest boundaries. Though we recognize that this buffer analysis was developed for the Amazon Basin, ecosystem structure and function on the Osa Peninsula are very

Year	Total forest area (km^2)	Total forest area (% landscape)	Mean forest island size (km^2)	Number of forest islands
1979	977.1	97.6	2.2	445
1987	913.9	91.3	2.4	3722
1997	896.1	89.5	0.7	1241

TABLE 1 Changes in landscape structure on the Osa Peninsula, Costa Rica.

	Deforestation (km^2)		
Period	1-km buffer	5-km buffer	10-km buffer
1979–1987	1.8	28.7	75.0
1987–1997	1.9	19.5	46.3

TABLE 2 The dynamics of deforestation on the Osa Peninsula, Costa Rica.

similar to those of the Amazon Basin. This approach was therefore considered appropriate. Fragmentation for the forest class was assessed using 3 basic metrics: total percentage of the landscape, mean forest area (at the patch level), and number of forest islands. A complete description of these fragmentation indicators can be found in McGarigal and Marks (1995).

A total of 52 control points were selected from fieldwork conducted in July 1998. Points were also verified using 1:40,000 aerial photography carried out in the same year. Points were georeferenced to Lambert Conformal Conic. Overall accuracy (Congalton 1991; Foody 2002) and the Tau coefficient (Ma and Redmond 1995) were estimated. Overall accuracy for forest–nonforest and the Tau coefficient were estimated to be 92% and 0.89, respectively. The Tau coefficient indicates that our classification systems produce a map on which 89% more pixels were classified correctly than would be expected by random assignment. This means that for forest–nonforest classification, we were correct 89% of the time.

Finally, we used a species distribution data set produced by the Costa Rica National Biodiversity Institute (INBio) to assess the effect of forest degradation on key species. This data set provides unique information on the spatial distribution (latitude and longitude) of tree and plant species of Costa Rica that are identified as endemic, threatened, and new to science (INBio, *Atta, sistema de información de INBio* data set 2002). A total of 184 endemic, 12 threatened, and 77 new-to-science species were identified for the Osa Peninsula using INBio's database. Species information was transformed to point topology, identification tags were added, and a 1-km buffer zone around all species outside the protected area was implemented using a geographic information system. We focused our analysis on species located outside the Corcovado National Park because a higher threat due to deforestation was expected in areas lacking conservation initiatives.

Results

We found important land cover changes on the Osa Peninsula during the last 21 years (Tables 1 and 2; Figure 1). The proportion of the peninsula covered by forest declined from 97% in 1979 to 91% in 1987 and to 89% by 1997. Total forest area declined from 977 km^2 in 1979 to 896 km^2 by 1997. Total forest loss during the study period was therefore 81 km^2. No deforestation was detected inside the Corcovado National Park itself, where most changes in forest cover were attributed to large gaps in the canopy produced by falling trees. The identification of these gaps detected in the Landsat imagery was performed using 1:40,000 aerial photography carried out during 1997 by INBio.

Outside the Corcovado National Park, overall deforestation rates declined from 1.5% per year for 1979–1987 to 0.83% per year for 1987–1997. Deforestation was most pronounced beyond 5 km of the National Park boundary, where land cover change is currently taking place on small forest islands created by previous frontal deforestation processes (Figure 1 and Table 2). The number of forest islands present outside the park

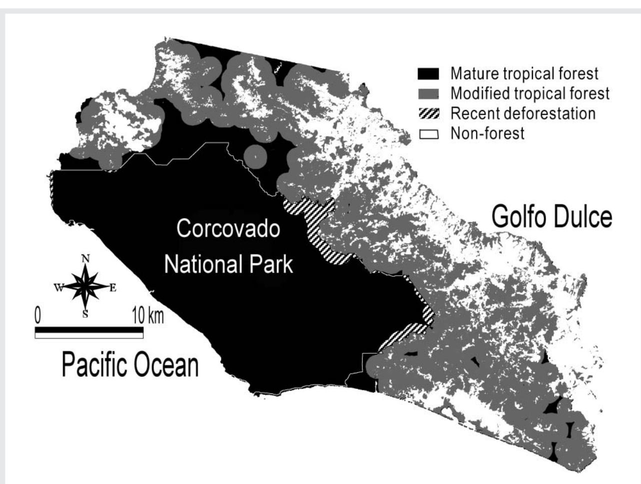

FIGURE 2 Extent of mature (dark) and modified (gray) tropical forest on the Osa Peninsula as of 1997. Of the remaining forest on the peninsula, 44% is considered altered (gray). The Corcovado National Park contains the vast majority of mature tropical forest. Currently, local deforestation processes occurring outside the park may be affecting up to 5% of the Corcovado National Park. (Map by authors)

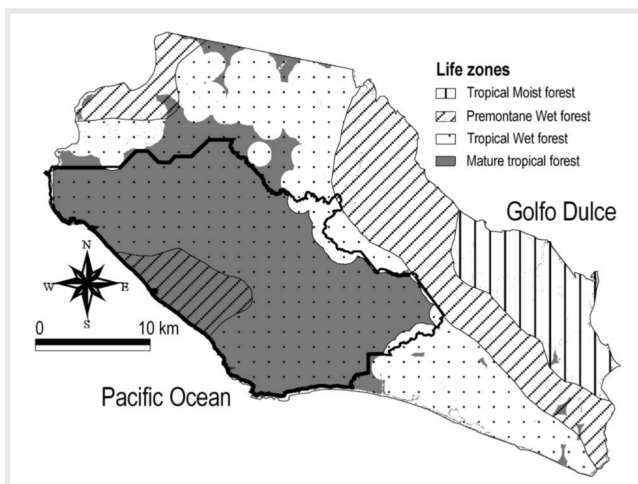

FIGURE 3 Extent of mature (dark gray) tropical forest for each life zone on the Osa Peninsula. The process of tropical deforestation has affected the 3 Holdridge life zones present on the peninsula. The effect on the Tropical Moist and Premontane life zones is very significant, with less than 2% of the mature forest (dark gray) remaining for each life zone. (Map by authors)

increased 8-fold between 1979 and 1987 (445–3722) but decreased to 1241 by 1997. The increase in forest islands between 1979 and 1987 was accompanied by an increase in the mean island size from 2.2 to 2.4 km^2. The mean island size dramatically decreased to 0.7 km^2 by 1997. Close to the National Park (within a 1-km buffer zone) deforestation was focused on primary mature forest, a process more cumulative than fragmentary.

Of the 3 Holdridge life zones observed on the Osa Peninsula, we estimated that only 34% of the original forest cover of the Tropical Moist forest remains as such. The forest cover of the Premontane Wet and Tropical Wet forest life zones is estimated to be 60% and 88% of their original extension, respectively. The Tropical Moist forest and the Premontane Wet forest are 2 life zones not protected by the Corcovado National Park and for these, average deforestation is estimated to be between 2.5% and 2.1% per year during the last 21 years. Using the 1-km buffer zone proposed by Skole and Tucker (1993), we estimated the total forest area degraded or affected by fragmentation within the Osa Peninsula to be 394 km^2 (approximately 44% of the current forest cover of the peninsula) (Figure 2). Only 1.5% (0.65 km^2) of the Tropical Moist forest and 1.9% (2.1 km^2) of the Premontane Wet forest remain as old growth, the remaining forest for these 2 life zones having been altered by frontal deforestation (Figure 3). Also using this criterion, we concluded that the effect of forest fragmentation has already reached the boundaries of the Corcovado National Park (Figure 2). We estimated that 4.6% (19.6 km^2) of the park area is affected by deforestation beyond its boundaries. The park protects the only remaining block of mature Tropical Wet forest in Mesoamerica.

Our species analysis indicates the presence of 4 clusters outside the Corcovado National Park for species that are threatened, endemic, and new to science. Cluster A (Figure 4) presents the higher concentration of species (over 50 species); cluster B presents a lesser concentration (17 species); clusters C and D are even less dense (10–12 species). Deforestation estimates indicate higher pressure in clusters A and B, with no significant forest loss in clusters C and D (Table 3). Total deforestation between 1979 and 1997 within the 1-km buffer for clusters A, B, C, and D is estimated to be 21.8, 5.3, 0.81, and 0.91 km^2, respectively.

Discussion and conclusions

The deforestation trends observed outside the Corcovado National Park indicate that the landscape of the Osa Peninsula has undergone significant change during the study period. Our research documents 2 different types of deforestation processes that are generally overlooked by nationwide deforestation studies. The first one indicates that deforestation outside and away from the park (>1 km) occurs largely on forest fragments. In contrast, deforestation close to the park (<1 km) is cumulative and frontal and affects the remaining mature forest. Our study also documents that as of 1997, only 44% of the forest remaining on the peninsula was mature and that most of the forest located outside the Corcovado National Park has been altered. The limited extent of forest resources on the Osa Peninsula, along with increased deforestation and timber harvesting from managed forests (selective extraction) in the areas surrounding the protected forest, will no doubt lead to the increased isolation of the park.

On the basis of estimates by Heindrichs (1997) and the Costa Rica National Forest Financing Fund for primary forests, the total loss of environmental services resulting from these processes has been in the order of US$ 8.5 million during the last 21 years. This figure does not take into account other environmental services provided by tropical ecosystems, such as drinking water purification, touristic and scenic appeal, secondary forest, or the genetic and pharmaceutical benefits of biodiversity.

Our results indicate that the Corcovado National Park currently protects 43% of the total forest cover in the region. The area of the forest protected by the park in addition to the unprotected forest outside the park totals 977 km^2 of the 1093 km^2 in the study area. This is considered less than the minimum acceptable for protecting some emblematic species that require large habitat areas to preserve their long-term genetic

TABLE 3 Forest loss and species distribution on the Osa Peninsula, Costa Rica.

Biodiversity cluster	Total number of identified species[1]	Deforestation 1979–1987 (km^2)	Deforestation 1987–1998 (km^2)	Total deforestation 1979–1998 (km^2)
A	>50	13.9	7.8	21.8
B	17	5.8	46.9	52.7
C	10	0.0	0.8	0.8
D	12	0.0	0.9	0.9

[1]Tree and plant species identified as threatened, endemic, and new to science. Source: INBio (2002).

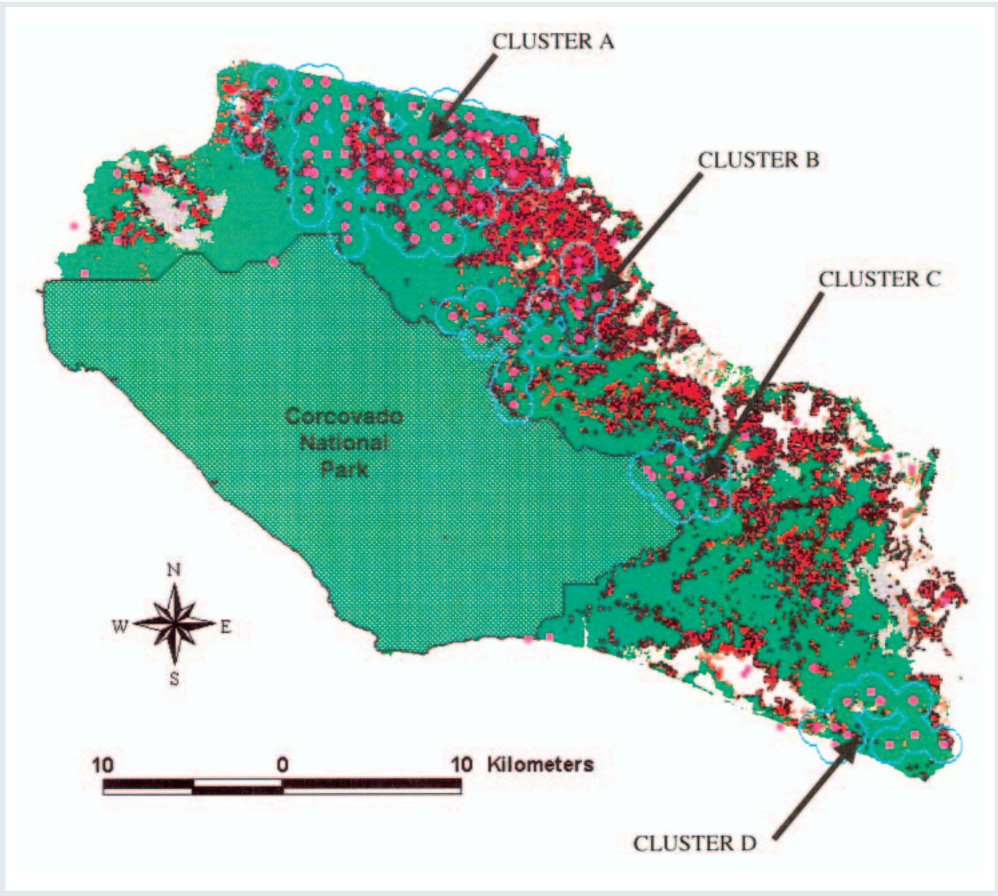

FIGURE 4 Spatial distribution of species that are threatened, endemic, and new to science outside the park. Four hotspots (A, B, C, D) can be identified, with a 1-km buffer zone around each documented location. The greatest deforestation can be observed in hotspot A, which contains the greatest number of species (Table 3).

integrity. For example, several habitat studies aimed at defining the home range and preference habitats for jaguars (*Panthera onca*) have estimated that this species (predominant on the Osa Peninsula) requires 30–140 km^2 per mature adult male to maintain a healthy population (Rabinowitz and Nottingham 1986; Crawshaw and Quigley 1991). In addition, it has been proposed by Palmeteri et al (2000) that a protected habitat must provide for at least 50 reproductive individuals to maintain a population, which for jaguars would imply a need to protect an area of at least 1500 km^2 (assuming a 30-km^2 home range). This exceeds the available mature forest area on the Osa Peninsula documented here. The lack of an adequate habitat area for jaguars on the Osa Peninsula may not only affect the long-term integrity of the jaguar population but may also have important ramifications for other species, given the significant predatory role of jaguars.

The presence of 4 species clusters on the Osa Peninsula in the context of deforestation trends indicates a strong need to evaluate the effectiveness of current conservation efforts in the region, specifically those related to payment for environmental services (eg, forest protection and sustainable forest management). In addition, increase and better enforcement of current legislation (Costa Rica's Forestry Law 7575) rather than new laws, as well as control of illegal deforestation, is critical to sustain the forest resources and biological diversity on the Osa Peninsula. The greater forest cover loss in areas with a high density of threatened, endemic, and new-to-science species poses a significant question regarding the success of future conservation initiatives outside protected areas. On the other hand, new research opportunities in tropical mountain environments could result from integrating species distribution maps into studies of deforestation trends to provide new means of planning conservation policies.

These scenarios indicate the need to design and implement a strategy for the conservation and development of the Osa Peninsula to: (1) stop the fragmentation and reduction of forest habitats; (2) promote their connectivity and habitat restoration; (3) adequately manage agricultural activities; and (4) promote research and management of species that require large protected areas or special measures to ensure their long-term survival.

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AUTHORS

G. Arturo Sanchez-Azofeifa and Benoit Rivard
Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, Alberta T6G 2E3, Canada.
arturo.sanchez@ualberta.ca (G.A.S.-A.) and benoit.rivard@ualberta.ca (B.R.)

Julio Calvo
Tropical Science Center, San José, Costa Rica, Central America.
jcalvo@cct.or.cr

Inian Moorthy
Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, Alberta T6G 2E3, Canada.

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