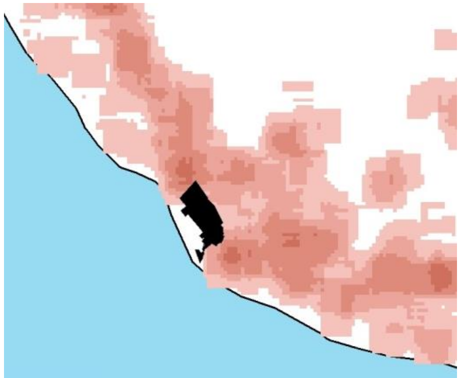
 

Investigating ecological patterns and processes in tropical forests using GIS and remote sensing

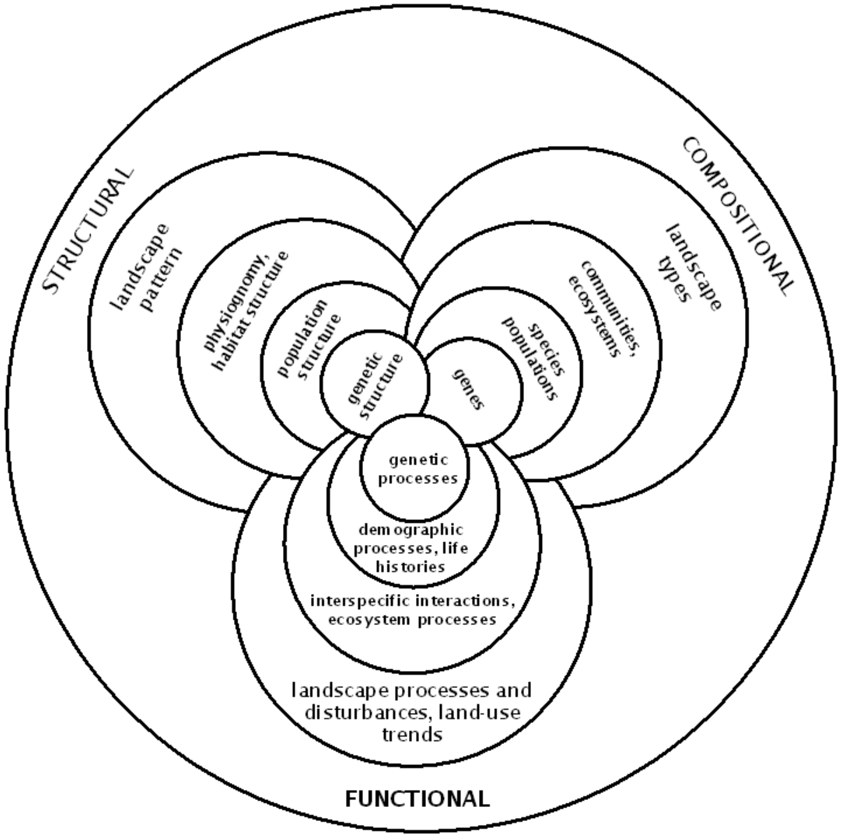
Carlos Portillo-Quintero
Center for Earth Observation Sciences (CEOS)
Department of Earth & Atmospheric Sciences
University of Alberta
November, 2013

Tropical Forests

"Tropical forests" encompass the idyllic rainforest, the remote cloud forest, and the lesser-known but equally endangered dry forest.

They are not one ecosystem, but a complex array of plant and animal communities.

They are the central nervous system of our planet -- a hotbed of evolution, life and diversity.

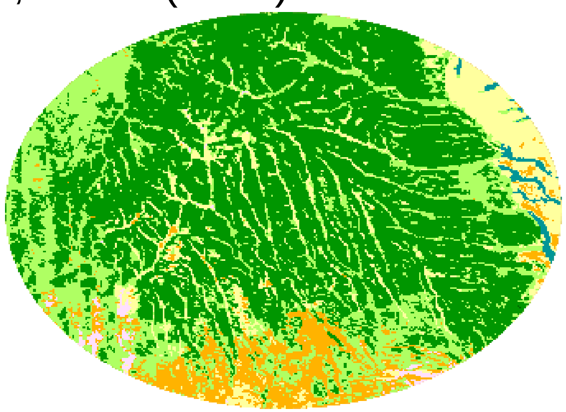


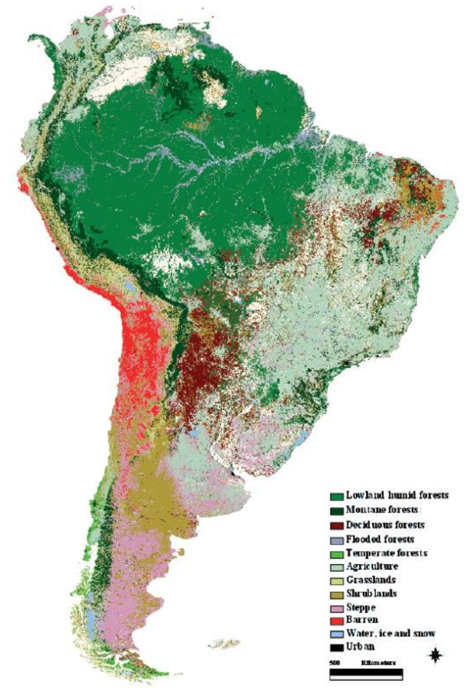
• “Biodiversity is the ensemble and the hierarchical interactions of the genetic, taxonomic and ecological scales of organization, at different levels of integration” (Di Castri & Younes, 1996)

Applied GIS and Remote sensing:
Conservation status and degradation drivers

- Ecosystem-scale analyses
- GIS databases at different scales: ecoregions, lifezones, vegetation types, vegetation density, etc.
- Multispectral passive sensors and products:

  AVHRR (1-km to 8-km)
  MODIS (250-m to 1-km)
  Landsat MSS, TM, ETM+ (30-m)
  ASTER (15-m)





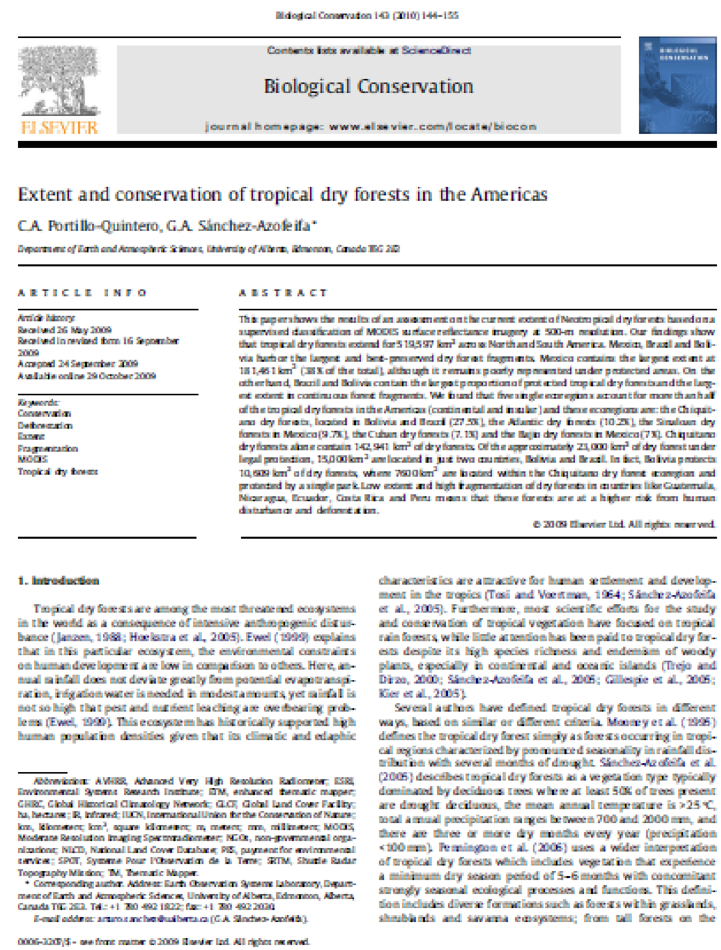
Applied GIS and Remote sensing:
Conservation status and degradation drivers of TF

- What is the extent and level of fragmentation of Tropical Deciduous forests?

- ERDAS, See5,
NLCD mapping tool, ArcGIS.

- TDF mapping based on
spectral and ancillary data

- Decision tree derived from
Machine learning algorithm.



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Extent and conservation of tropical dry forests in the Americas

C.A. Portillo-Quintero, G.A. Sánchez-Azofeifa*

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

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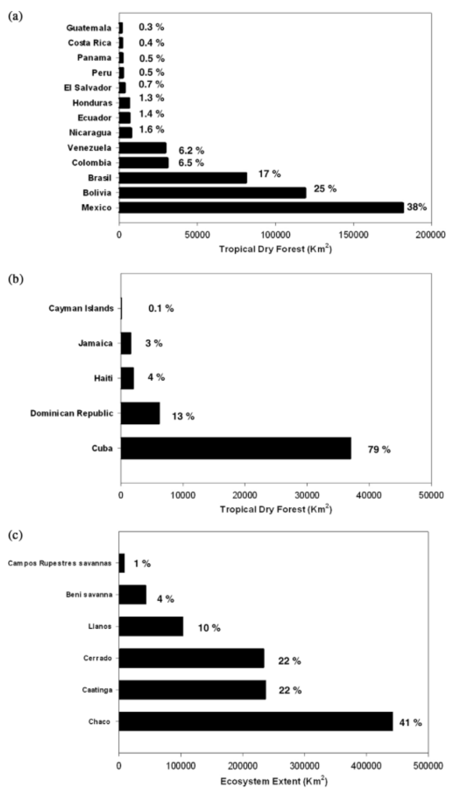
ABSTRACT

This paper shows the results of an assessment on the current extent of Neotropical dry forests based on a supervised classification of MODIS surface reflectance imagery at 500-m resolution. Our findings show that tropical dry forests extend for 519,597 km² across North and South America. Mexico, Brazil and Bolivia harbor the largest and best-preserved dry forest fragments. Mexico contains the largest extent at 181,461 km² (38% of the total), although it remains poorly represented under protected areas. On the other hand, Brazil and Bolivia contain the largest proportion of protected tropical dry forests and the largest extent in continuous forest fragments. We found that five single ecoregions account for more than half of the tropical dry forests in the Americas (continental and insular) and these ecoregions are: the Chiquitano dry forests, located in Bolivia and Brazil (27.5%), the Atlantic dry forests (10.2%), the Sinaloan dry forests in Mexico (9.7%), the Cuban dry forests (7.1%) and the Bajio dry forests in Mexico (7%). Chiquitano dry forests alone contain 142,941 km² of dry forests. Of the approximately 23,000 km² of dry forest under legal protection, 15,000 km² are located in just two countries, Bolivia and Brazil. In fact, Bolivia protects 10,609 km² of dry forests, where 7600 km² are located within the Chiquitano dry forest ecoregion and protected by a single park. Low extent and high fragmentation of dry forests in countries like Guatemala, Nicaragua, Ecuador, Costa Rica and Peru means that these forests are at a higher risk from human disturbance and deforestation.

1. Introduction

Applied GIS and Remote sensing: Conservation status and degradation drivers

- What is the extent and level of fragmentation?



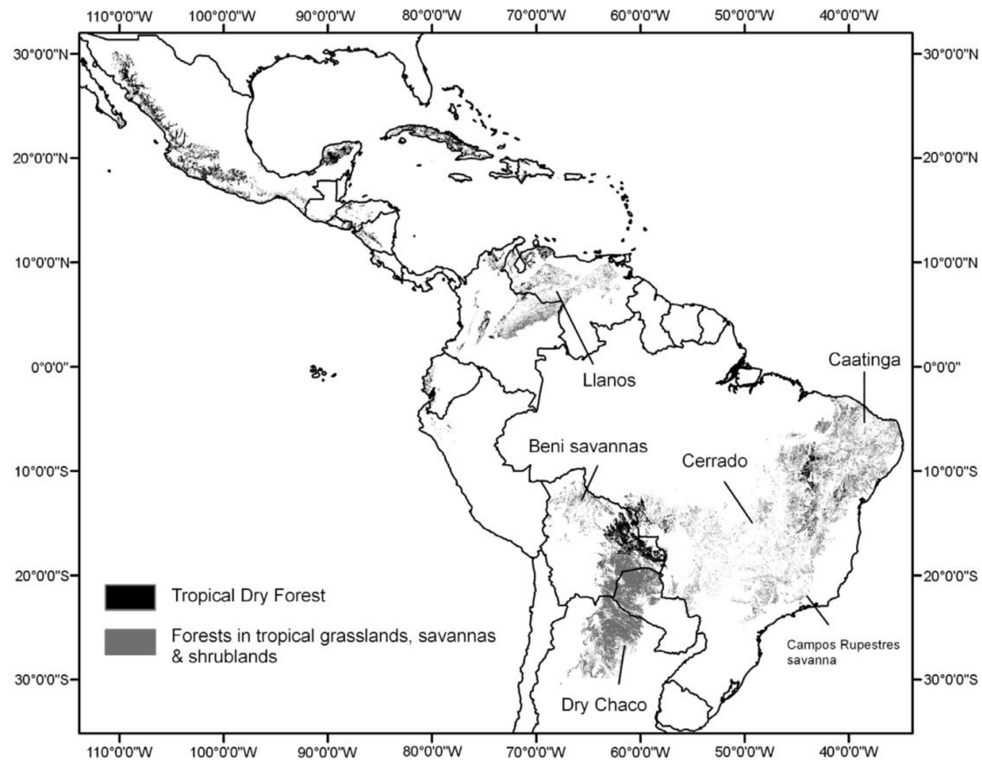
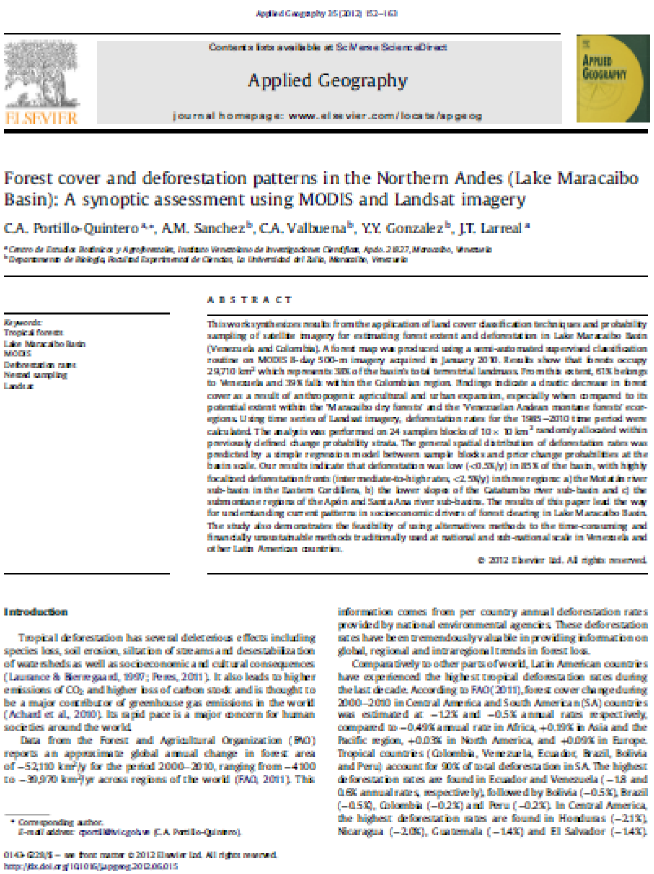


Table 1
Current tropical dry forest extent (km^2) derived from MODIS 500-m data and area under protected areas at three levels: (a) North, Central and South American countries; (b) countries of the Caribbean islands and (c) summary of results per subregion.

Country	TDF potential extent (based on Olson et al., 2001)	TDF current extent (this analysis)	TDF converted (%)	TDF Protected (km^2)	Percentage under protection
(a)					
Mexico	625,038	181,461	71	336	0.2
Bolivia	216,031	118,940	45	10,609	8.9
Brazil	168,164	81,046	52	5015	6.2
Venezuela	113,143	29,396	74	302	1.0
Colombia	92,664	30,713	67	1555	5.1
Peru	48,914	2337	95	188	8.1
Nicaragua	32,277	7414	77	–	–
Honduras	26,582	6280	76	–	–
Ecuador	25,275	6443	75	147	2.3
El Salvador	11,291	3344	70	9	0.3
Guatemala	10,431	1463	86	-	-
Costa Rica	7559	1795	76	279	15.6
Panama	6160	2128	65	-	-
Total	1383,529	472,759	66	18,620	3.9
(b)					
Subregion					
N&C America	719,338	203,884	72	624	0.3
South America	664,191	268,875	60	17,816	6.6
C. Islands	137,130	46,839	66	4797	10.2
Total	1520,659	519,597	66	23,417	4.5
(c)					
Country					
Cuba	109,879	36,996	66	4023	10.9
Dominican	14,669	6194	58	368	6.0
Haiti	8971	2002	78	0	0
Jamaica	3438	1585	54	400	25
Cayman Islands	173	63	64	3.5	5.6
Total	137,130	46,839	66	4797	10.2

Applied GIS and Remote sensing: Conservation status and degradation drivers

- Spatial patterns of deforestation rates
- Lake Maracaibo Basin, Northern Andes.
- Assessment using MODIS and Landsat Imagery
- ArcGIS, ENVI, Geospatial Modelling Environment



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Forest cover and deforestation patterns in the Northern Andes (Lake Maracaibo Basin): A synoptic assessment using MODIS and Landsat imagery

C.A. Portillo-Quintero [a,*], A.M. Sanchez [b], C.A. Valbuena [b], Y.Y. Gonzalez [b], J.T. Larreal [a]

[a] Centro de Estudios Botánicos y Agroforestales, Instituto Venezolano de Investigaciones Científicas, Apdo. 21827, Maracaibo, Venezuela
[b] Departamento de Biología, Facultad Experimental de Ciencias, La Universidad del Zulia, Maracaibo, Venezuela

Keywords:
Tropical forests
Lake Maracaibo Basin
MODIS
Deforestation rates
Nested sampling
Landsat

A B S T R A C T

This work synthesizes results from the application of land cover classification techniques and probability sampling of satellite imagery for estimating forest extent and deforestation in Lake Maracaibo Basin (Venezuela and Colombia). A forest map was produced using a semi-automated supervised classification routine on MODIS 8-day 500-m imagery acquired in January 2010. Results show that forests occupy 29,710 km^2 which represents 38% of the basin's total terrestrial landmass. From this extent, 61% belongs to Venezuela and 39% falls within the Colombian region. Findings indicate a drastic decrease in forest cover as a result of anthropogenic agricultural and urban expansion, especially when compared to its potential extent within the 'Maracaibo dry forests' and the 'Venezuelan Andean montane forests' ecoregions. Using time series of Landsat imagery, deforestation rates for the 1985–2010 time period were calculated. The analysis was performed on 24 samples blocks of 10 × 10 km^2 randomly allocated within previously defined change probability strata. The general spatial distribution of deforestation rates was predicted by a simple regression model between sample blocks and prior change probabilities at the basin scale. Our results indicate that deforestation was low (<0.5%/y) in 85% of the basin, with highly focalized deforestation fronts (intermediate-to-high rates, <2.5%/y) in three regions: a) the Motatán river sub-basin in the Eastern Cordillera, b) the lower slopes of the Catatumbo river sub-basin and c) the submontane regions of the Apón and Santa Ana river sub-basins. The results of this paper lead the way for understanding current patterns in socioeconomic drivers of forest clearing in Lake Maracaibo Basin. The study also demonstrates the feasibility of using alternatives methods to the time-consuming and financially unsustainable methods traditionally used at national and sub-national scale in Venezuela and other Latin American countries.

Introduction

Tropical deforestation has several deleterious effects including species loss, soil erosion, siltation of streams and desestabilization of watersheds as well as socioeconomic and cultural consequences (Laurance & Bierregaard, 1997; Peres, 2011). It also leads to higher emissions of CO_2 and higher loss of carbon stock and is thought to be a major contributor of greenhouse gas emissions in the world (Achard et al., 2010). Its rapid pace is a major concern for human societies around the world.

Data from the Forest and Agricultural Organization (FAO) reports an approximate global annual change in forest area of −52,110 km^2/y for the period 2000–2010, ranging from −4100 to −39,970 km^2/yr across regions of the world (FAO, 2011). This information comes from per country annual deforestation rates provided by national environmental agencies. These deforestation rates have been tremendously valuable in providing information on global, regional and intraregional trends in forest loss.

Comparatively to other parts of world, Latin American countries have experienced the highest tropical deforestation rates during the last decade. According to FAO (2011), forest cover change during 2000–2010 in Central America and South America (SA) countries was estimated at −1.2% and −0.5% annual rates respectively, compared to −0.49% annual rate in Africa, +0.19% in Asia and the Pacific region, +0.03% in North America, and +0.09% in Europe. Tropical countries (Colombia, Venezuela, Ecuador, Brazil, Bolivia and Peru) account for 90% of total deforestation in S.A. The highest deforestation rates are found in Ecuador and Venezuela (−1.8 and 0.6% annual rates, respectively), followed by Bolivia (−0.5%), Brazil (−0.5%), Colombia (−0.2%) and Peru (−0.2%). In Central America, the highest deforestation rates are found in Honduras (−2.1%), Nicaragua (−2.0%), Guatemala (−1.4%) and El Salvador (−1.4%).

* Corresponding author.
E-mail address: cportill@ivic.gob.ve (C.A. Portillo-Quintero).

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Applied GIS and Remote sensing: Conservation status and degradation drivers

- Spatial patterns of deforestation rates

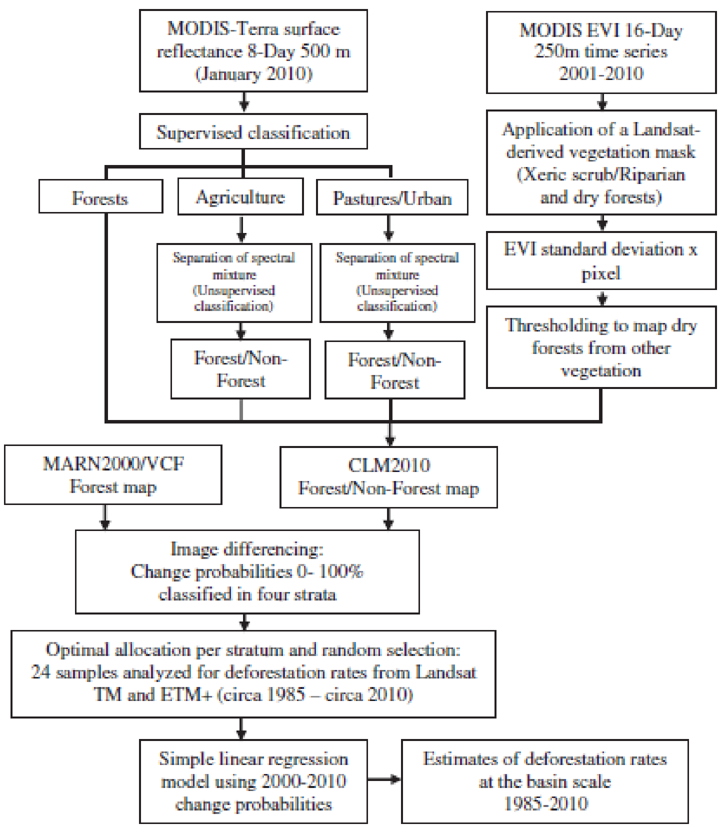


Fig. 3. Schematic of methods used in this study.

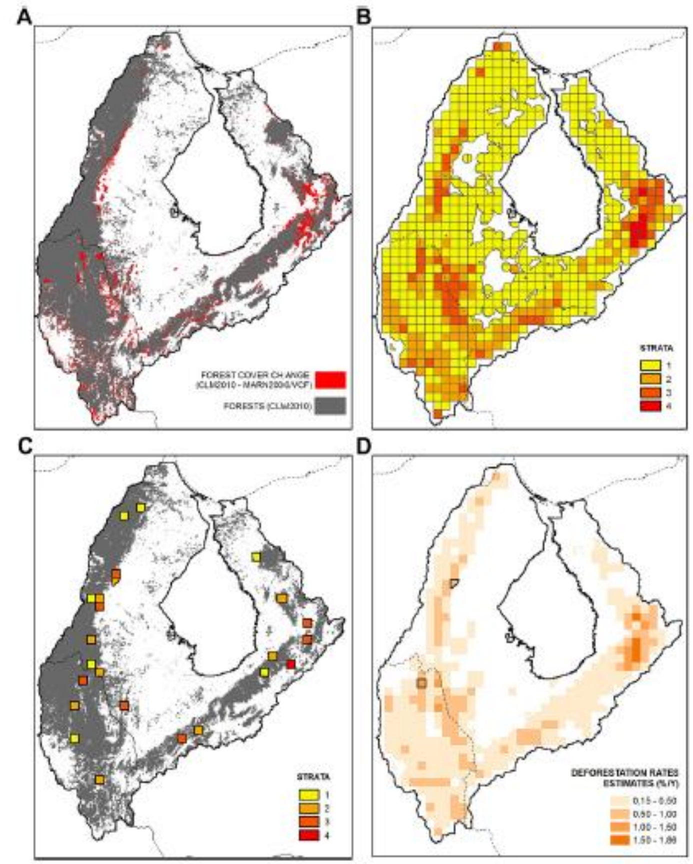


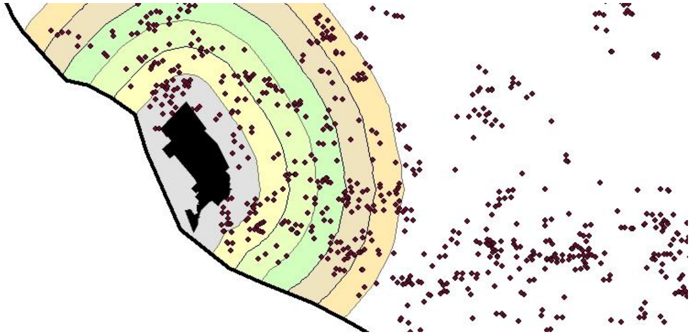
Fig. 5. a) Map indicating areas of forest change after comparing the MARN2000/VCF and the CLM2010 dataset; b) predicted change probabilities calculated for 10 × 10 km^2 blocks within 5 km of all mapped forests ($n = 377$). Values were classified in four strata using the Jenks optimization method. c) Sample blocks selected per stratum using Neyman optimal allocation. Deforestation rates were calculated per sample block using Landsat scenes from 1985 to 2010, d) deforestation rates estimated for 377 blocks based on a simple linear regression model using calculated deforestation rates and MARN2000–CLM2010 change probability values ($R^2 = 0.29$, $p < 0.05$; Rd = 0.0263[change prob] + 0.1482). The two sample blocks showing the highest deforestation rates (>2%/y) are highlighted with black line boundaries.

Applied GIS and Remote sensing: Conservation status and degradation drivers

- What socioeconomic factors affect reserve effectiveness?

- Tropical forest reserve effectiveness for controlling deforestation fires.

- MODIS Active Fires inside/outside TF reserves



Ecological Applications, 17(5), 2007, pp. 1259–1266

POVERTY AND CORRUPTION COMPROMISE TROPICAL FOREST RESERVES

S. Joseph Wright,[1,4] G. Arturo Sanchez-Azofeifa,[2] Carlos Portillo-Quintero,[2] and Diane Davies[3]

[1] *Smithsonian Tropical Research Institute, Apartado 0843-03092, Balboa, Republic of Panama*
[2] *Earth and Atmospheric Sciences Department, University of Alberta, Edmonton, Alberta T6G 2E3 Canada*
[3] *Department of Geography, University of Maryland, 2181 LeFrak Hall, College Park, Maryland 20742 USA*

Abstract. We used the global fire detection record provided by the satellite-based Moderate Resolution Imaging Spectroradiometer (MODIS) to determine the number of fires detected inside 823 tropical and subtropical moist forest reserves and for contiguous buffer areas 5, 10, and 15 km wide. The ratio of fire detection densities (detections per square kilometer) inside reserves to their contiguous buffer areas provided an index of reserve effectiveness. Fire detection density was significantly lower inside reserves than in paired, contiguous buffer areas but varied by five orders of magnitude among reserves. The buffer : reserve detection ratio varied by up to four orders of magnitude among reserves within a single country, and median values varied by three orders of magnitude among countries. Reserves tended to be least effective at reducing fire frequency in many poorer countries and in countries beset by corruption. Countries with the most successful reserves include Costa Rica, Jamaica, Malaysia, and Taiwan and the Indonesian island of Java. Countries with the most problematic reserves include Cambodia, Guatemala, Paraguay, and Sierra Leone and the Indonesian portion of Borneo. We provide fire detection density for 3964 tropical and subtropical reserves and their buffer areas in the hope that these data will expedite further analyses that might lead to improved management of tropical reserves.

Key words: biodiversity; corruption; fire; Indonesia; national parks; poverty; protected areas; remote sensing; tropical forest; wealth.

Introduction

Tropical deforestation is among the greatest threats to the preservation of global biodiversity (Millennium Ecosystem Assessment 2005). Tropical and subtropical nations have created an immense system of nature reserves to ameliorate this threat. The World Database on Protected Areas (WDPA), which is incomplete, delineates the boundaries of 1938 reserves that encompass 1.63×10^6 km^2 of forest between the Tropics of Cancer and Capricorn alone (WDPA Consortium 2004). Just these nationally recognized reserves represent 7.3% of the preagricultural extent of tropical forest and 15% of extant tropical forest (Ramankutty and Foley 1999, Achard et al. 2002, Hansen and DeFries 2004). Indigenous areas, reserves recognized by subnational levels of government, and nationally recognized reserves not yet entered into the WDPA will all increase the total area protected (Nepstad et al. 2006). Collectively these reserves should make a substantial contribution to the conservation of biodiversity in the tropics.

There is considerable debate, however, about the effectiveness of these protected areas, with concern that many tropical reserves are ineffective "paper parks" unable to protect the biodiversity within their borders against growing anthropogenic pressure (Terborgh et al. 2002, Smith et al. 2003a, Curran et al. 2004). Recent studies indicate that many tropical reserves do reduce the impact of a wide range of human activities including grazing, hunting, fire, logging, and forest clearing (Bruner et al. 2001, Vanclay et al. 2001, DeFries et al. 2005, Nepstad et al. 2006); however, we still lack a global assessment of the effectiveness of all tropical forest reserves. Here, we use the global fire detection record provided by the satellite-based Moderate Resolution Imaging Spectroradiometer (MODIS) to determine whether protected status influences fire occurrences for every tropical reserve with boundaries delineated in the WDPA.

We limit our analyses to moist forests because natural fire return times can extend to centuries in tropical moist forests, and human activities increase fire frequency above these low background levels (Cochrane 2003). Human activities that increase fire frequency include timber extraction and land use conversion. Timber extraction increases fuel loads and dries forest microclimates (Cochrane 2003). Forest clearing creates forest–field edges and remnant forest fragments that are highly susceptible to fire (Cochrane 2003, Laurance 2004). Fire is also used purposefully to clear forest, to control natural regrowth, and to manage agricultural lands (Kull 2004, Rudel 2005). Thus, fire provides an indicator of timber extraction and land use conversion that moist

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[4] E-mail: wrightj@si.edu

Applied GIS and Remote sensing: Conservation status and degradation drivers

- What socioeconomic factors affect reserve effectiveness?

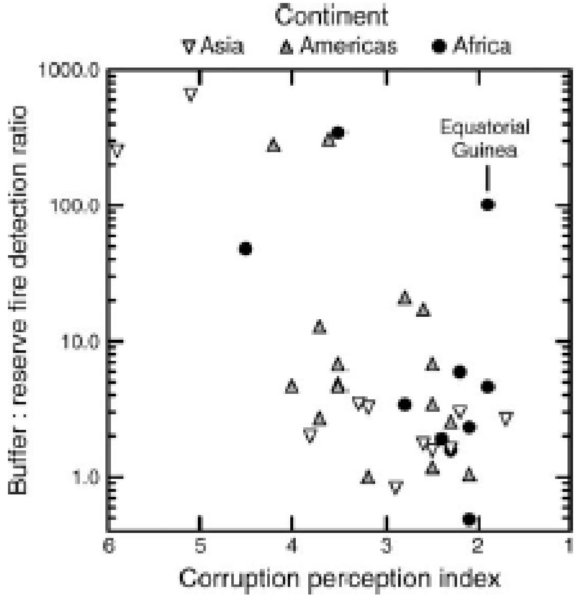


FIG. 3. The linear relationship ($r^2 = 0.37$, $P < 0.001$) between the median buffer : reserve fire detection ratio for moist forest reserves in the 37 countries depicted in Fig. 2 (note log scale) and the corruption perception index (CPI). The horizontal scale is reversed because the CPI takes values near 1 for the most corrupt countries and values near 10 for the least corrupt countries (Poroznuk 2005). Two data points were moved slightly to become visible.

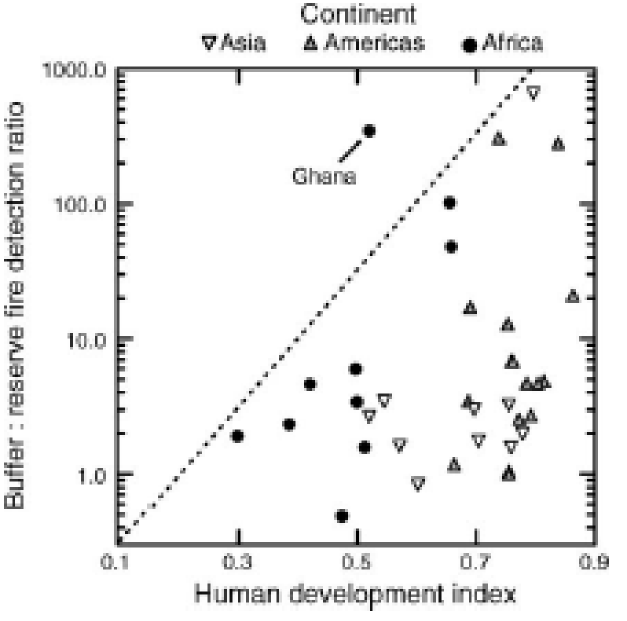


FIG. 4. The triangular relationship between the median buffer : reserve fire detection ratio for moist forest reserves in the 37 countries depicted in Fig. 2 (note log scale) and the human development index. The human development index ranges from a low of 0.281 for Niger to a high of 0.963 for Norway (UNDP 2005). The arbitrary dashed line highlights the triangular relationship with Ghana as the sole exception.

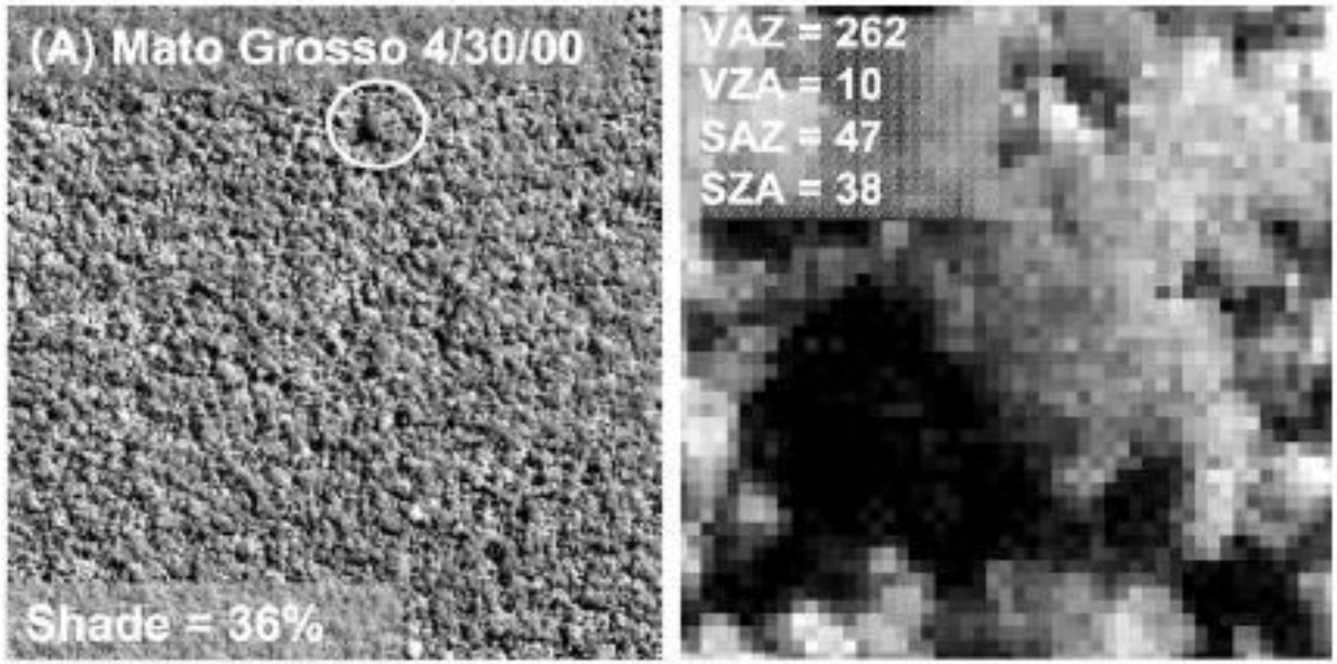
Applied GIS & RS: Structural diversity

Ecosystem structural variation is closely related to species presence/absence and species diversity patterns

Ecological niche theory holds that macrospatial and microspatial heterogeneity are important sources of high species diversity (Kohner 2001; Ricklefs 2000).

Asner & Wagner (2003)

Dominated by variations in crown size and dimensions, stand density, crown architecture, leaf area index, leaf optical properties, and viewing and solar geometry.



•De Wasseige (2002): NIR reflectance band of Landsat TM and SPOT satellites provide the best picture of canopy variability.

•Pasher et al. (2007) also used shadow fractions to detect gaps in the forest in order to predict nesting sites for the hooded warbler (*Wilsonia citrina*) – Landsat TM

Applied GIS & RS

- Structural diversity

LiDAR Sensors are capable of using their return signals to detect the height of the canopy top, ground elevation, and the positions of leaves and branches in between

M. Castillo-Núñez et al. / Remote Sensing of Environment 115 (2011) 2217–2231 2225

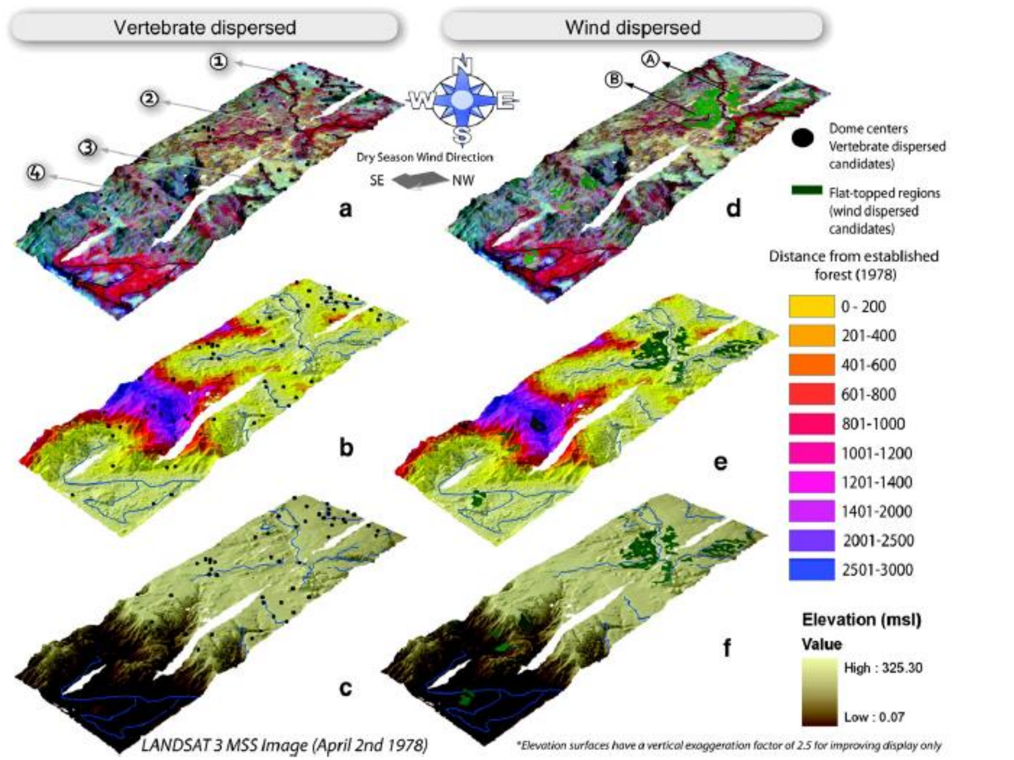
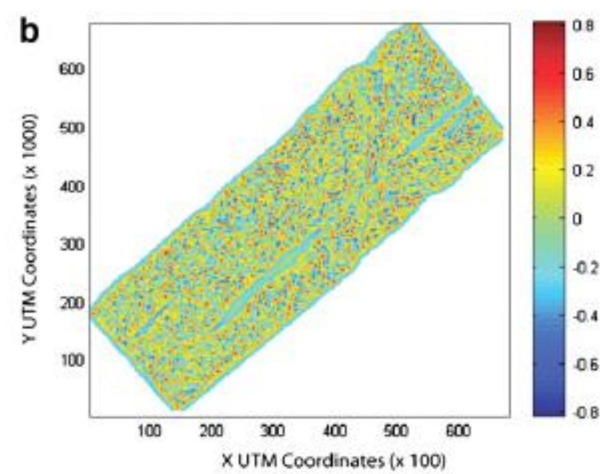


Fig. 5. Dome shape and flat top candidate regions shown in the context of previously established forest, wind direction and topography. Section 5a shows the location of the dome shape candidates on top of the LANDSAT 7 MSS image, and the possible location of former pasturelands (in numbers 1–4), section 5b shows (in color scale) the distance from forests established before 1978, section 5c shows the topography of the site, the dome-shaped candidates and the location of forest in 1978 (light blue lines). Fig. 5d, e, f show the same data but with the flat top candidate regions on top of each dataset (flat top candidates shown as dark green polygons).

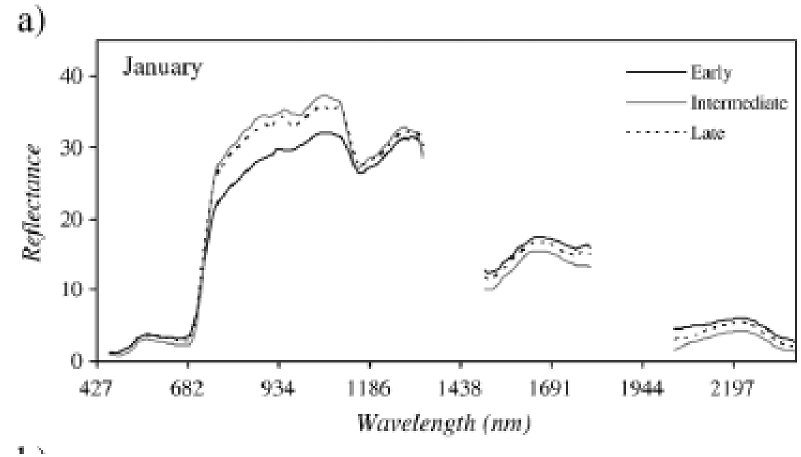


Center for Earth Observation Sciences (CEOS)

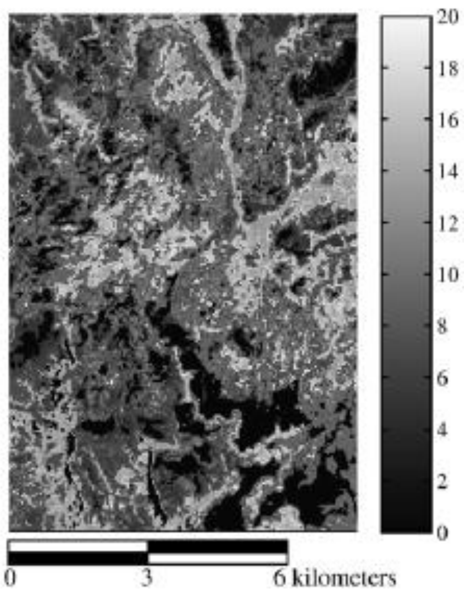
Applied GIS & RS

- Structural diversity

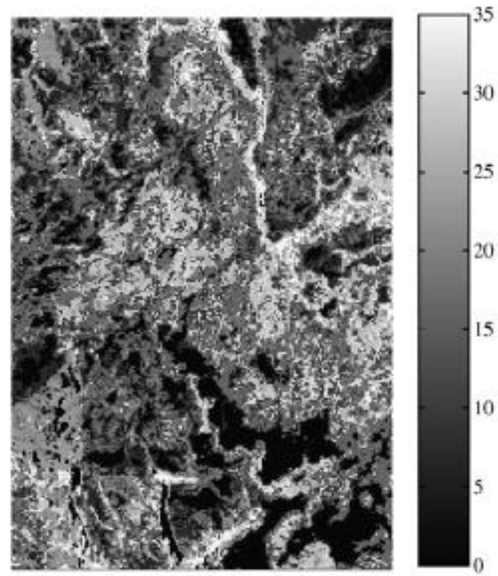
Kalacska et al. 2007 used Hyperion (Hyperspectral sensor) and field measurements of Forest structure to identify forest regrowth



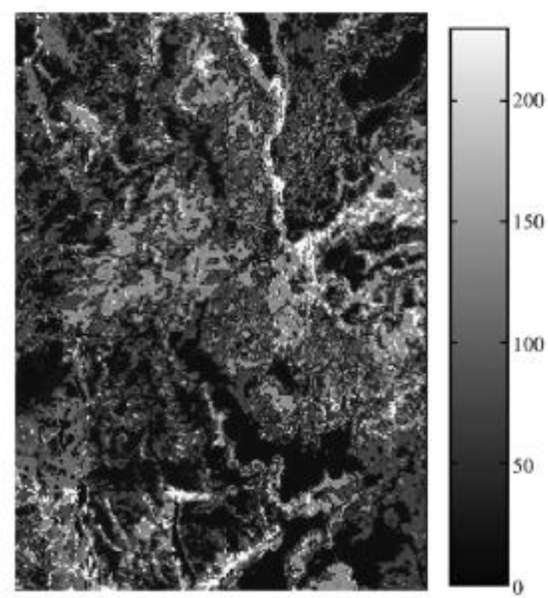
Tree Canopy Height



Tree Basal area



Holdridge Complexity Index

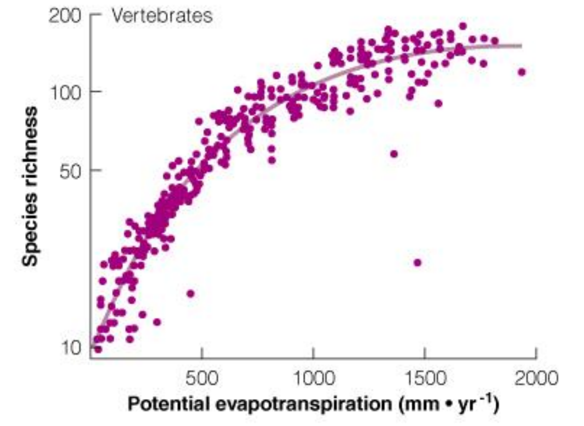


Center for Earth Observation Sciences (CEOS)

Applied GIS & RS

- Functional and biochemical diversity

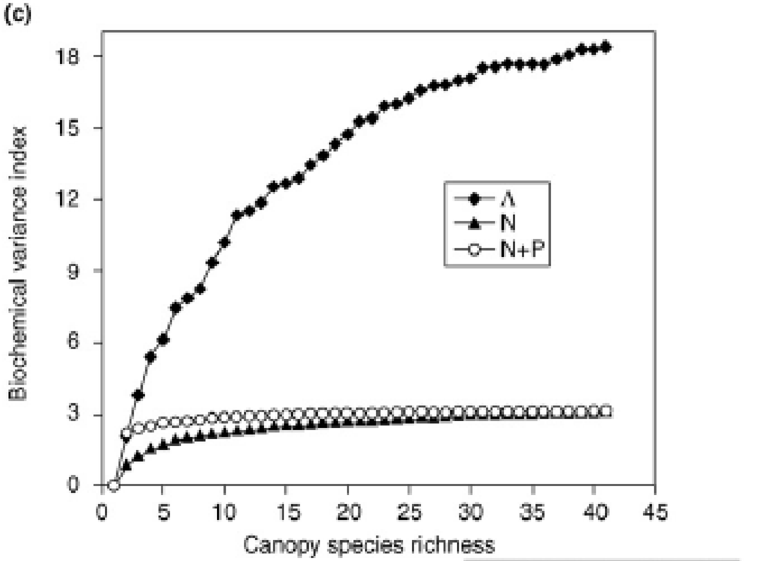
- Primary productivity and potential evapotranspiration predicts species richness



(b)

- Biochemical properties such as pigment and nutrient concentration have been linked to species richness and diversity

(c)



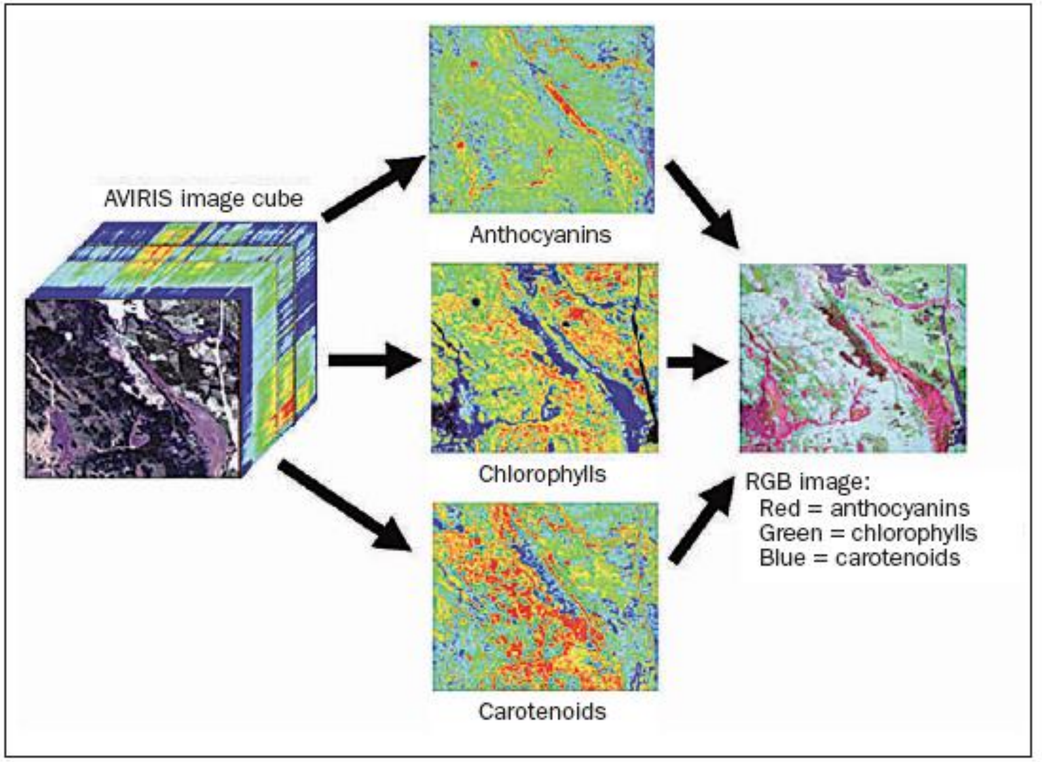
TRENDS in Ecology & Evolution

Applied GIS & RS

- Functional and biochemical diversity
- Biochemical diversity

The work from Townsend et al. (2008) and Asner et al. (2008) suggest that chemical, physiological and structural variation of tropical forest canopies is driven by species diversity.

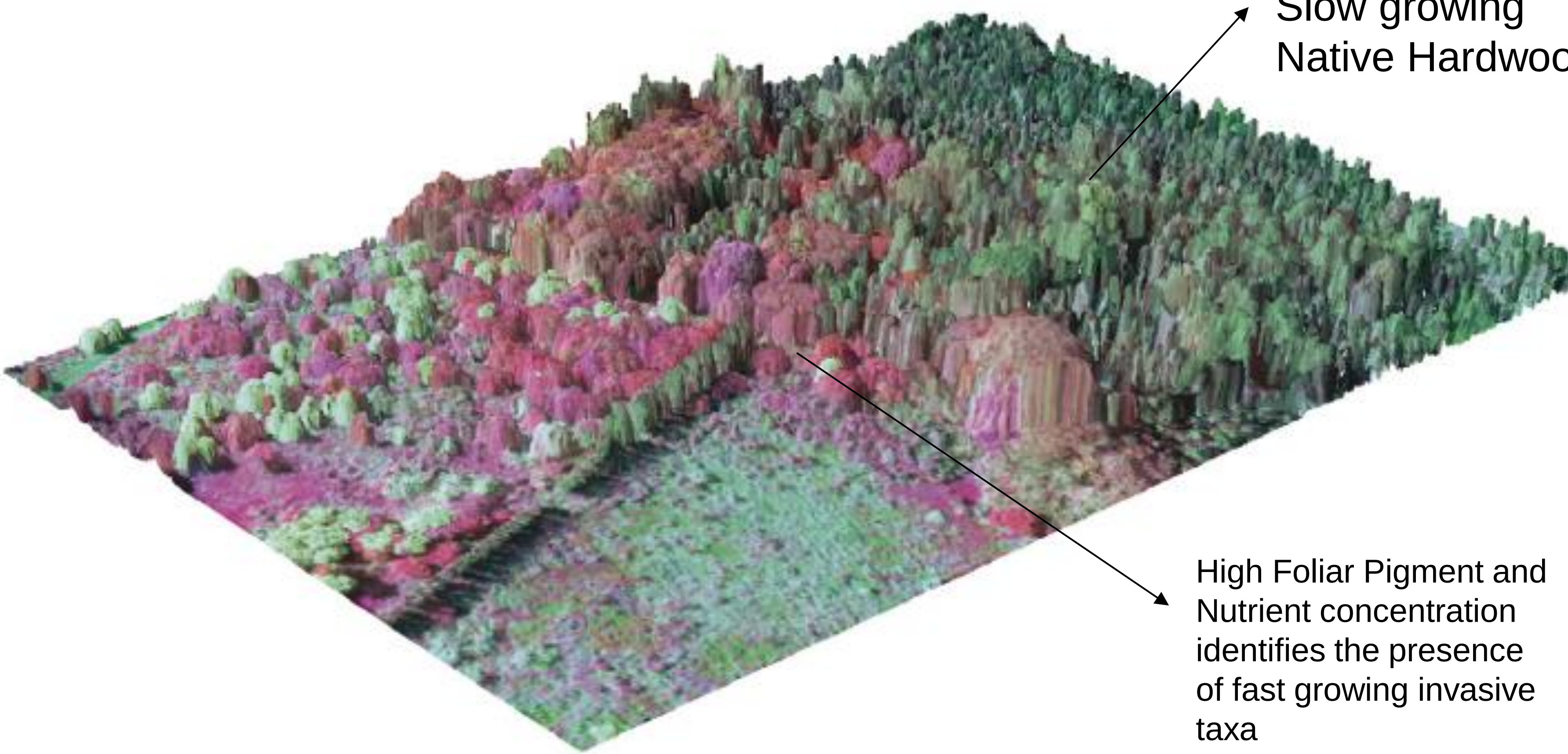
Gamon (2008) suggests that measures of “optical diversity” from biophysical and biochemical sensitive spectral bands should link with independent measures of in-situ species diversity



Soil Organic matter Content, Iron Content
AVIRIS

Applied GIS & RS

- Functional and biochemical diversity



Canopy height, crown size and Chemical Diversity Map (Townshend, 2008)

Applied GIS & RS

• Taxonomic diversity:

<u>Ecological niche modeling</u>

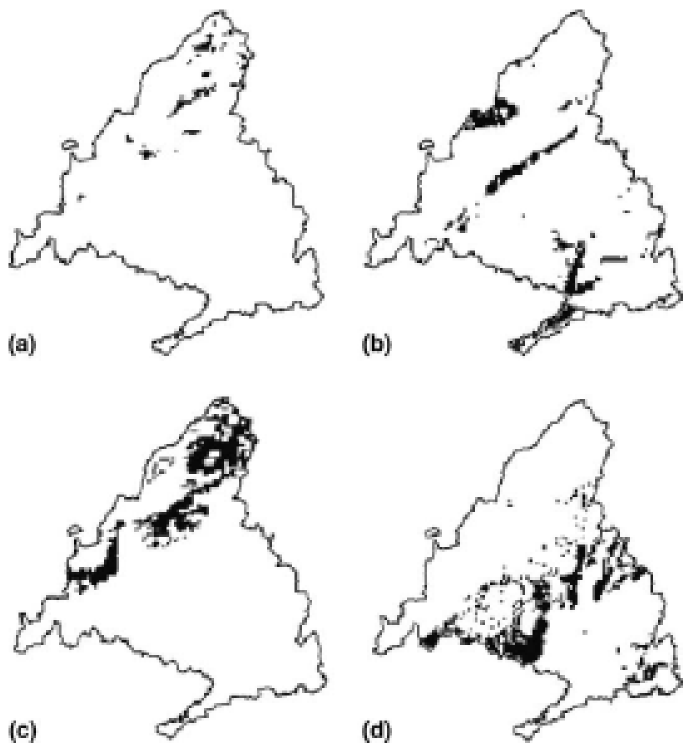
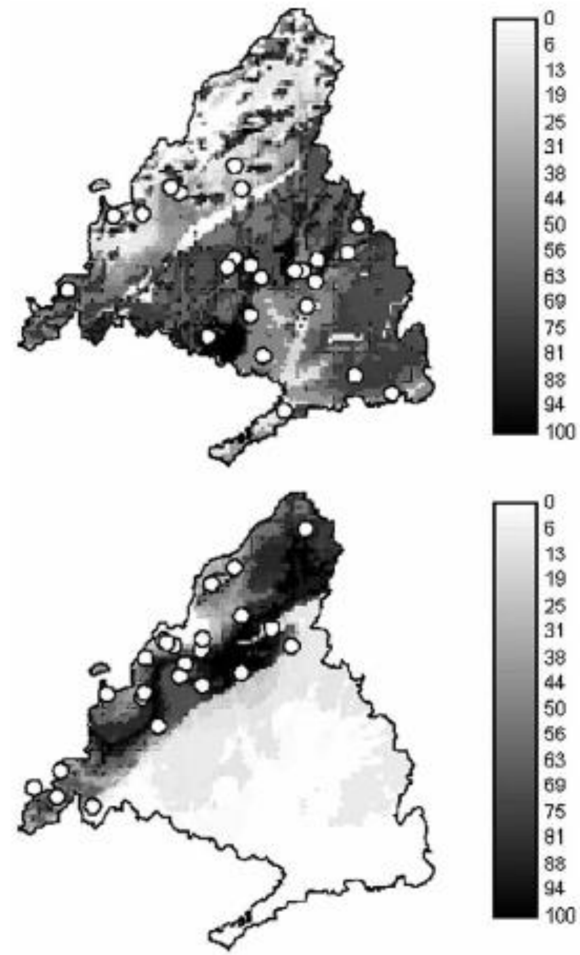


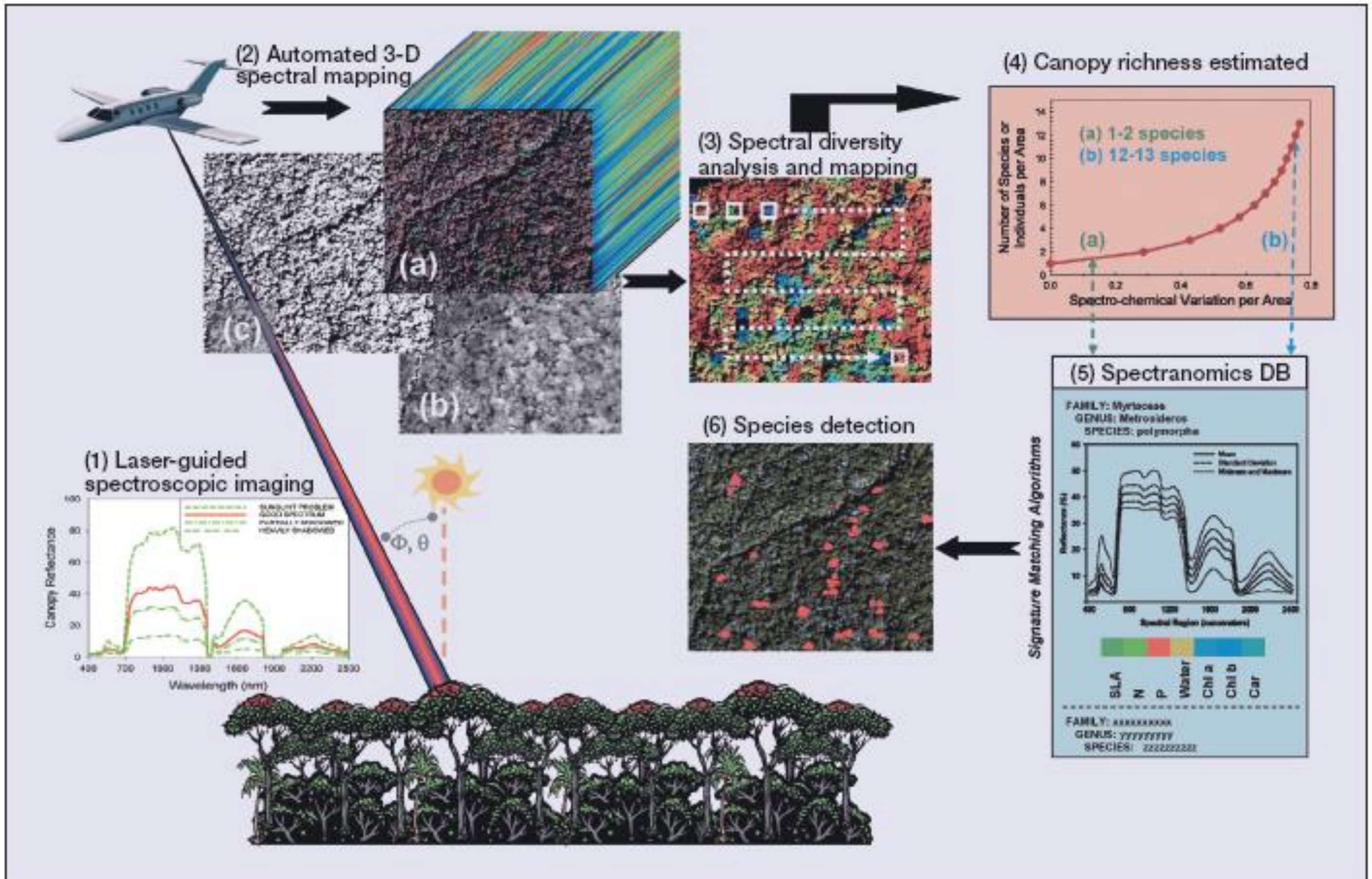
Fig. 3. Maps of areas that are: (a) very highly suitable for both species; (b) very poor for both species; (c) very poor suitability for *C. hispanus* and very high for *C. lunaris*; (d) very highly suitable for *C. hispanus* and very poorly for *C. lunaris*.



Habitat suitability maps for C. hispanus and C. lunarius (Chefaoui, 2005) using Biomapper

Applied GIS & RS

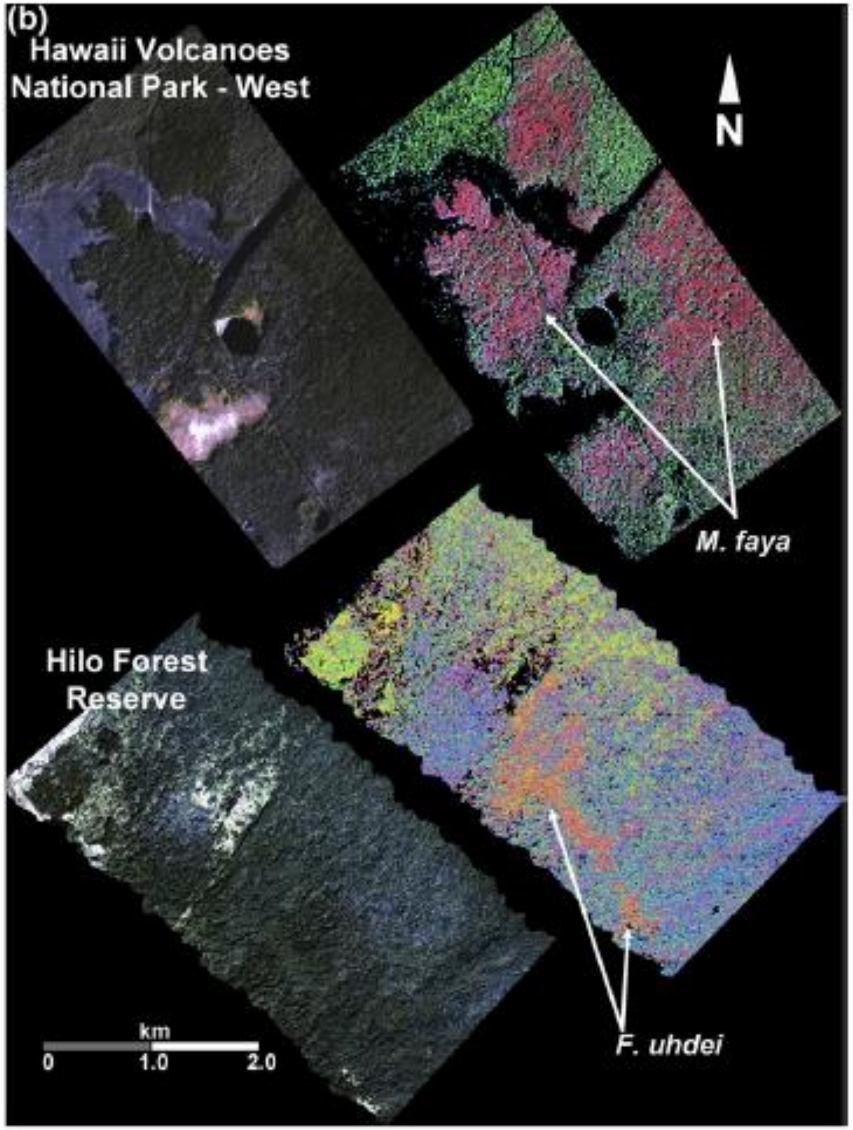
- Taxonomic diversity



Spectranomics (Asner, 2008)

Applied GIS & RS

- Taxonomic diversity



Spectranomics (Asner, 2008)

The future of GIS/RS applications in Tropical forests

- Specialized research centers in the tropics
- Integration of Open-source modules or working environments
- Application of novel techniques at the ecoregional level
- Hypertemporality
- Integration with in-situ sensors and real-time data processing (Live maps)