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Forest Clearance and Fragmentation in Palawan and Eastern Mindanao Biodiversity Corridors (1990-2000): A Time Sequential Analysis of LANDSAT Imagery

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This article reports on a portion of an applied conservation research project entitled "Defining and Monitoring Conservation Outcomes for the Philippines", which was funded by the Critical Ecosystems Partnership Fund (CEPF), part of which applied a particular remote sensing technique in another country setting.

Abstract

Conservation International has mapped changes in forest cover in the Philippines over large areas in two biodiversity corridors, as defined by the Critical Ecosystems Partnership Fund (CEPF). These changes were derived by analyzing Landsat satellite imagery at a spatial resolution of 28.5 m. The dataset analyzed includes Landsat 5 data from circa 1990 (+/- 3 years) and Landsat 7 data from circa 2000. Image dates were determined based on the availability of free, nearly cloud-free imagery from the University of Maryland's Global Land Cover Facility (http://glcf.umiacs.umd.edu/index.shtml). Additional scenes were also purchased for areas most heavily covered with clouds. A supervised classification approach was employed, using a decision tree classifier. The total amount of forest cleared during the time period was 20.1 km^2 in the Eastern Mindanao corridor and 37.5 km^2 in the Palawan biodiversity corridor, representing an average annual forest clearance rate of 0.04 percent for Eastern Mindanao and 0.07 percent for Palawan. Forest fragmentation was also observed to be more apparent in Palawan due to clearance of smaller forest patches. Forest cover interpretation from the Landsat imagery was validated through a collective aerial system of videography and photography. The combined accuracy of the classified maps was 85.4 percent.

Keywords: aerial videography, biodiversity application, decision tree classifier, fragmentation statistics, remote sensing

Abbreviations:

CEPF	Critical Ecosystems Partnership Fund
ETM+	Enhanced Thematic Mapper Plus
GPS	Global Positioning System
IR	Infrared
KBA	Key biodiversity area
LANDSAT	Refers to an earth-observing satellite program jointly managed by NASA and the United States Geological Survey to gather specialized digital pictures of the Earth's surface from space.
mid-IR	Middle infrared
miniDV	miniature digital video
RMS	Root mean square
SLR	Single lens reflex
SMPTE	Society of Motion Picture and Television Engineers
TM	Thematic Mapper
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
VCR	Video cassette recorder

Introduction

The Philippines is considered one of the most important countries in the world for biodiversity conservation. It is one of the few countries, which is both a megadiversity country (with more than 20,000 endemic species of plants and animals) and a biodiversity hotspot (i.e. its high biodiversity is under a high level of threat). Yet the Philippines is experiencing a high rate of biodiversity loss in spite of its importance. Despite continued efforts from the government, non-government agencies, and international development banks, forest cover has declined over the years due to social, institutional, economic, and political influences (WWF, 1998). Deforestation in the Philippines is due to natural (flashfloods and landslides) and human (logging and land-use conversion into either settlement or agriculture) factors. This has largely contributed to the degradation of the country's biodiversity resources. In addition to the direct effects brought about by forest removal, indirect effects like habitat fragmentation and resulting edge effects greatly magnify the problems associated with deforestation.

In June 2005, a national workshop on monitoring for terrestrial biodiversity held in Subic expressed the need for institutionalizing monitoring and evaluation (M&E) systems for measuring biodiversity conservation successes and continued threats. A major output of the workshop was a list of biodiversity indicators and a tool set for measuring the indicators, which can be a basis for evaluating conservation performance. One of the indicators included in the list was status of species habitat. In a subsequent "writeshop" in November 2005, members of the steering committee of the Subic workshop firmed up the list of these indicators and developed guidelines for a national monitoring protocol. The habitat indicator then evolved into several sub-indicators to assess habitat quality and quantity, e.g., water quality and quantity, carbon storage, habitat alteration, and change in forest cover. Although the committee was able to identify the minimum set of indicators and corresponding tools on how to measure them, there were no details on the steps or methodology involved. Moreover, there were no readily identifiable sources for appropriate baseline data or information on these indicators. The problem with the existing forest cover data in the Philippines today is that there is no baseline information for purposes of monitoring forest loss over a given time.

Concepts of the study

The aim of this study is to establish and verify a baseline dataset of forest cover and forest loss to be used for calculating and monitoring deforestation and fragmentation trends in Eastern Mindanao and Palawan. The following discusses the concepts used in accomplishing this aim.

Remote sensing

Remote sensing has provided a valuable tool for the rapid assessment of changes in forest cover over time. This is important because accurate information regarding land use and land cover change is relevant to decision makers and planners. Remotely sensed data can provide important land cover information for estimating levels and rates of deforestation, habitat fragmentation, urbanization, wetland degradation, and many other landscape-level phenomena. Such information can, in turn, be incorporated into many regional to global-scale models (Vogelmann et al., 2001). Recent monitoring strategies of high-biodiversity areas in Asia-Pacific, Europe and the Americas are utilizing remote sensing as a primary monitoring tool. The basis for identifying different surface components in remote sensing is that all objects reflect, absorb and transmit incident light differently. Specialized satellites orbiting the earth have digital sensors that detect these variations by collecting multiple wavelengths of reflected or emitted light in defined regions of the electromagnetic spectrum. These 'spectral signatures' can then be manipulated and statistically analyzed to determine the unique characteristics of the landscape and produce information such as land cover and/or forest cover.

Different classification algorithms were developed to derive image-based land cover during the last decade. Among the popular remote sensing techniques are maximum likelihood, neural networks and decision trees. Comparing the aforementioned classifiers, the advantage of a decision tree classifier for remotely sensed data is its computational efficiency, nonparametric nature, simplicity, and robustness with respect to non-linear and noisy relations among input features and class labels (Pal and Mather, 2001). It also provides lower statistical error than the maximum likelihood classifier (MLC) (JARS, 1996). In addition, MLC becomes rapidly inefficient as the number of attribute dimensions increases and gives poor classification accuracy due to statistical data requirements (German et al., 1999).

It is important to know the accuracy of image-derived results. The level of confidence of a remote sensing product can be derived through statistical estimates of error where data are sampled against 'ground truth' information (a validation process). Classification accuracy is commonly evaluated with the use of an error matrix or what is sometimes referred to as contingency or confusion matrix (Card, 1982; Congalton, 1991). To obtain unbiased verification and validation data, airborne video data system was utilized to collect ground data information (Graham, 1993). This alternative process provides a cost-sensitive and time-effective procedure over large geographic areas such as Palawan and Eastern Mindanao (Slaymaker et al., 1996), assesses the accuracy of Landsat-based forest-change detection, and assists in the final interpretation of the forest-cover change maps (Juhn and Pereira, 2006).

In this study, remote sensing techniques were employed to successfully interpret the satellite imagery obtained from the Landsat 5 Thematic Mapper (TM) and Landsat 7 Enhanced Thematic Mapper Plus (ETM+) sensors and derive the changes in forest cover. The decision tree classifier was used to discriminate spectral classes into two major cover types as "forest" and "non-forest" and identify changes over a 10-year period. To rapidly but effectively monitor changes in forest cover, a corridor-wide analysis was adopted from

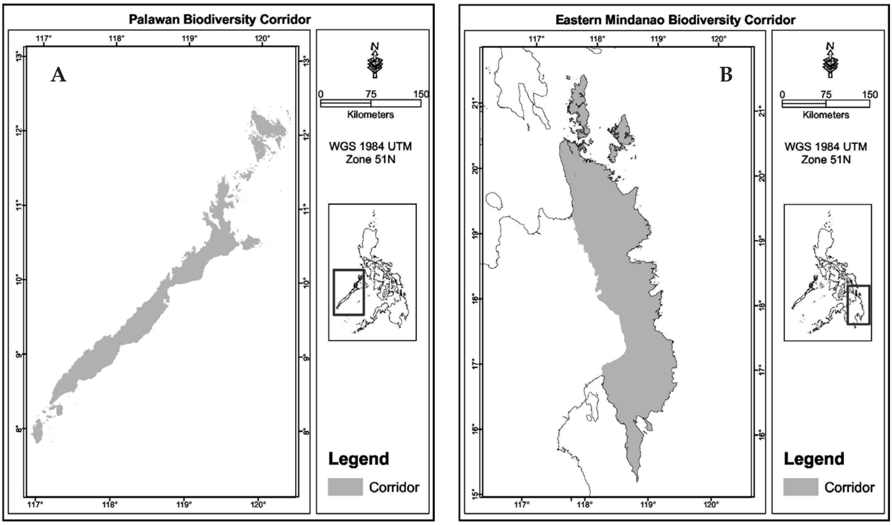

Figure 1. Two major conservation corridors. (Palawan Biodiversity Corridor [A] and Eastern Mindanao Biodiversity Corridor [B] were monitored for changes in forest cover from 1990 to 2000.)

the Level I Classification of the Land Use, Land Cover Classification System, which derives broad classes of land cover such as "forest", "non-forest", water and mangrove with minimal assistance from supplemental information. The analysis was done for the two major biodiversity areas in the Philippines, namely, Palawan and Eastern Mindanao corridors (Figure 1). The changes in forest cover were calculated over a 10-year period from 1990 to 2000.

Habitat fragmentation

Fragmentation occurs when a large region of habitat is broken down into smaller patches leading to habitat degradation and conversion. Habitat fragmentation can threaten species' survival by: (1) reducing total habitat area and, consequently, decreasing availability of food and other resources to the population; (2) edge-effects which degrade the habitat; and (3) lost connectivity to adjacent habitats.

Materials and Methods

The study areas and data used are explained below. Methods used in this study were adapted from the work of Steininger et al. (2006).

The study areas

Palawan

The Palawan biodiversity corridor, with approximately 1.5 million hectares of land comprised of more than 1,700 islands and islets, is a complex ecosystem that serves as refuge to some 106 globally important terrestrial and marine species. Palawan often is called the Philippines' "last biodiversity frontier", because it still retains more than 50 percent of its original forest cover (Conservation International, 2006).

Eastern Mindanao

One of the largest remaining blocks of dipterocarp forest in the country is found along the eastern portion of Mindanao. Plant diversity in the corridor comprises more than 2,300 plant species–some 31 percent of the Philippines' total. Of these, 60 percent are endemic to the corridor and this account for 29 percent of Philippines' total endemics (Conservation International, 2006).

Image preparation

Landsat images covering the corridors in Eastern Mindanao and Palawan were downloaded for free from the University of Maryland's Global Land Cover Facility. The majority of these images were provided in the GeoCover format, meaning that they had been georeferenced to a coordinate system and ortho-rectified using a digital elevation model. Those scenes not in GeoCover format were coregistered to the GeoCover scene using at least 30 ground control points and an RMS error of less than 1 pixel. Additional scenes were purchased from USGS to fill in cloud-contaminated areas, and were similarly processed. Once all data were coregistered and projected to the UTM coordinate system, a single 2-date file was created by combining the circa 1990 data with the circa 2000 data. This generated a single, 12-band file with the first six bands representing the 'first year' (1990s) and the last 6 bands representing the 'last year' (2000s) (Table 1).

All images were viewed as pseudo-color combinations of bands 4, 5 and 3 (infrared (IR), mid-IR, and red, respectively). The analyst found that this combination best separates mature forests from other vegetation such as agricultural fields and shrublands. Training areas, sample areas of predetermined cover types using local knowledge of the region and analyst's interpretation of the image, were then delineated and assigned unique values in each image pair for forest, non-forest, forest loss, water, mangrove, clouds, and shadow (Table 2). The training data were thereafter used as input for a decision

Table 1. List of satellite images used for (a) Palawan and (b) Eastern Mindanao and its sources: Basic Science and Remote Sensing Initiative (BSRSI); Global Land Cover Facility (GLCF); U.S. Geological Survey (USGS)

(a) Landsat Image Data – Palawan

Scene			1990s			2000s	
Path	Row	Date	% Cloud	Source	Date	% Cloud	Source
116	52	1/17/1989	5	GLCF	12/28/2001	10	GLCF
alternate scene					7/18/2000	25	GLCF
alternate scene					10/4/1999	50	GLCF
116	53	7/2/1991	50	GLCF	12/28/2001	15	GLCF
alternate scene		12/9/1991	60	USGS	5/21/2002	25	GLCF
117	53	2/12/1990	15	GLCF	9/9/1999	20	GLCF
alternate scene		12/5/1987	10	BSRSI	2/5/2002	12	GLCF
alternate scene					5/22/2000	20	GLCF
117	54	3/5/1989	25	GLCF	4/7/2001	10	GLCF
alternate scene		6/12/1993	10	GLCF	9/9/1999	18	GLCF
alternate scene		2/12/1990	10	BSRSI	7/31/2002	15	GLCF
118	54	9/25/1988	12	GLCF	9/16/1999	12	GLCF

(b) Landsat Image Data – Eastern Mindanao

Scene			1990s			2000s	
Path	Row	Date	% Cloud	Source	Date	% Cloud	Source
111	55	1/22/1989	70	USGS	12/4/1999	11	GLCF
					7/21/2002	15	GLCF
					12/4/1999	0	GLCF
112	53	no first date			10/8/1999	10	GLCF
					9/8/2000		GLCF
					6/10/2002	19	GLCF
112	54	8/1/1992	20	GLCF	5/22/2001	5	GLCF
alternate scene		8/17/1992	30	USGS	12/3/2002		GLCF
					8/7/2000		GLCF
					10/8/1999		BSRSI
112	55	12/31/1989	20	GLCF	5/22/2001	10	GLCF
alternate scene		8/17/1992		USGS	12/3/2002		GLCF

Table 2. Land-cover class description

Class	Description
Forest	Vegetative communities comprised principally of trees potentially over 10m in height and frequently characterized by closed or multi-layered canopies.
Non-forest	Land cover comprised of urban, rural, agricultural and other open areas.
Water	Inland body of water, lakes and river system.
Mangrove	Trees and shrubs that grow in saline coastal habitats.
Unknown	Composed of cloud and shadow data as interpreted from the classification results

tree that created rules for defining each individual class or subclass based on the spectral values of each Landsat band. This process is described in the next section.

The decision tree classifier

A decision tree classifier is a multistage or sequential, hierarchical decision scheme that breaks up a complex decision into a union of several simpler decisions (Pal and Mather, 2001). It uses fairly simple binary tree classifiers that divide the data into two branches, separated by a node. The classification tree interprets a dataset consisting of features with corresponding attributes, in this case a shapefile of polygons with unique codes for each subclass of cover type. The major advantages of this process are that there is the assumption of data normality, the process is easy to interpret, and the classification results are more accurate and faster to produce than a statistical classifier such as maximum likelihood.

Ground validation using aerial surveys

An aerial survey campaign was conducted to acquire systematic video and photographic imagery for validating and assessing the accuracy of our Landsat-based, forest-change detection. Data collected from the aerial surveys were also used to assist in the final interpretation of Landsat imagery, prior to completion of the classified map. The flight path for the aerial survey was chosen based on the criteria listed below: (1) areas that were difficult to interpret in the Landsat imagery and required further investigation; and (2) representative areas in terms of land cover type and condition.

Three types of data were collected during the aerial survey: (1) digital camera photo samples; (2) continuous digital videography; and (3) local expert observations. The video-data acquisition system was comprised of several cameras mounted on a Cessna 206 aircraft that flew at a low altitude between 700 and 2000 ft. above ground level. Hardware included a camera mount, a 35-mm digital SLR camera (Nikon D100), a video camera recorder (Canon Elura), handheld GPS units (Garmin), laptop computer (Sony Vaio), Horita time code generator, and a video monitor (Figure 2). Geographic position data were recorded from the GPS unit to the laptop computer using GeolinkTM software. Time code was acquired from the GPS data stream by a Horita GPS time code generator to provide a matching SMPTE time code to the VCRs (R. Pargee, Horita, Inc., personal communication). SMPTE time code is the standard audible

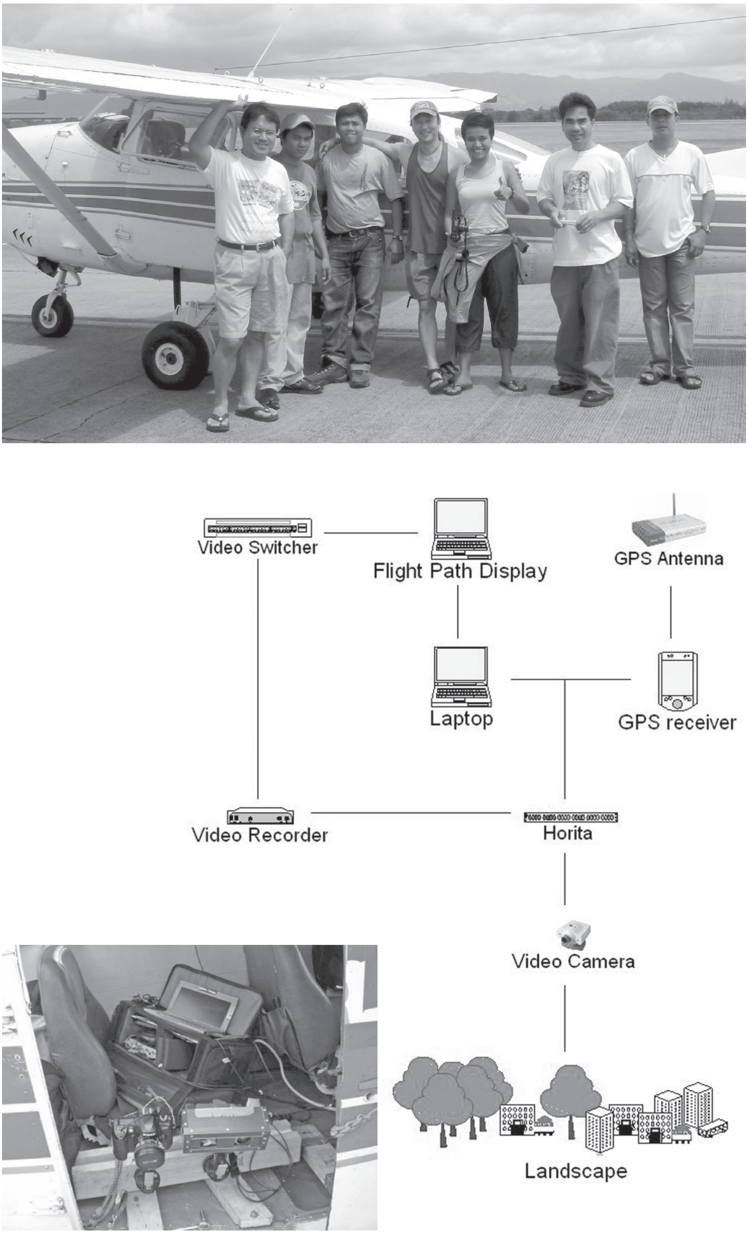

Figure 2. Airborne video system equipment set-up used to collect ground truth data

timing signal recorded to the audio track of video. Horita's time code generator substitutes GPS time for the normal internally generated signal, allowing each frame to be matched to a geographic position. We recorded the time code directly onto the video images, as well as the audio track, to simplify the synchronization with the miniDV tapes during playback. The video frames were each matched with their geographic positions using time code imprinted on the videotape during flight (Juhn and Pereira, 2006).

The 35-mm and digital-camera photo samples were used for aiding interpretation during the supervised training process, while the continuous videography was used for ground-truthing and contextual mapping. A local botanical expert was also invited on the overflight to provide vegetation knowledge throughout the surveys. Their observations were coordinated with the logged GPS data.

Accuracy assessment

Accuracy was assessed using an error matrix with an array of numbers organized in rows and columns, which expresses the number of sample units (i.e., pixels and clusters of pixels) assigned to a particular category relative to the actual category as indicated by reference data (Congalton, 1991). We applied the matrix method by comparing the classified data derived from the decision tree classifier with the ground data gathered from the aerial survey. The accuracy, therefore, is a measure of how many ground truth pixels were correctly classified.

The product of the above method is a matrix whose columns represent the ground-truthed pixels, while the rows represent the classified pixels, and where each column and row refers to the categories of the classification used. The diagonal elements of the matrix are the number of times the two data sets agree. Non-diagonal elements give the numbers of misclassified items by category. Individual classes were measured for producer's and user's accuracy as well as overall accuracy. Kappa-coefficients represent the proportion of agreement obtained after removing the proportion of agreement that could expect to occur by chance (Foody, 1996). Kappa-hut values lie on a scale from 0 to 1 in which the latter indicates complete agreement. It is the measure of the difference between the observed agreements of two maps. To give better percentage measure of the classification accuracy, the values were multiplied by 100.

Statistical analysis

Basic statistics were calculated on the amount of forested area per corridor, as well as the amount of forest loss and the rate of forest loss for each corridor. In addition, the degree to which forests occur in isolated patches and the degree to which forests occur near 'edges' of non-forest habitat were also calculated.

Results and Discussion

Classification accuracy

The classified satellite image data was compared to ground data collected from the aerial survey following defined flight paths (Figure 3). Results of the classification are shown in Figure 4. The error matrix in Table 3 provides an estimate of the correlation between ground data and the classified map values.

In Palawan, producer's accuracy, ranges between 95 to 100 percent while user's accuracy ranges between 93 to 100 percent. The overall accuracy is 96 percent and the kappa-coefficient is 0.9310 or 93.10 percent, indicating a strong agreement. In Eastern Mindanao, producer's accuracy ranges from 65 to 100 percent while user's accuracy ranges from 50 to 100 percent. The overall accuracy is 75 percent and the kappa-coefficient is 0.5773 or 57.73 percent, indicating only a moderate agreement. The large discrepancy between the two corridors is likely the result of several factors. Most importantly, the vegetation in Eastern Mindanao is very difficult to map due to its mosaic of mature forest patches and degraded lands. This causes difficulty in interpretation for the analyst, as well as difficulty in classification for the decision tree classifier, because the spectral values of some forested areas are very close to those of secondary growth and degraded lands. Moreover, because many of the forested areas are in patches, even slight errors in the alignment of the video data with the GPS coordinates can cause errors in the accuracy assessment process, resulting in lower accuracy values.

Change in forest cover

Total forest cover within the Eastern Mindanao corridor is approximately 30 percent, whereas in Palawan, forests cover nearly half of the island. The main focus of this study was to determine rates of deforestation within the corridors; however, to most accurately determine those rates, we utilized a two-date change detection methodology whereby we mapped deforestation directly. This is an important distinction between typical change detection studies,

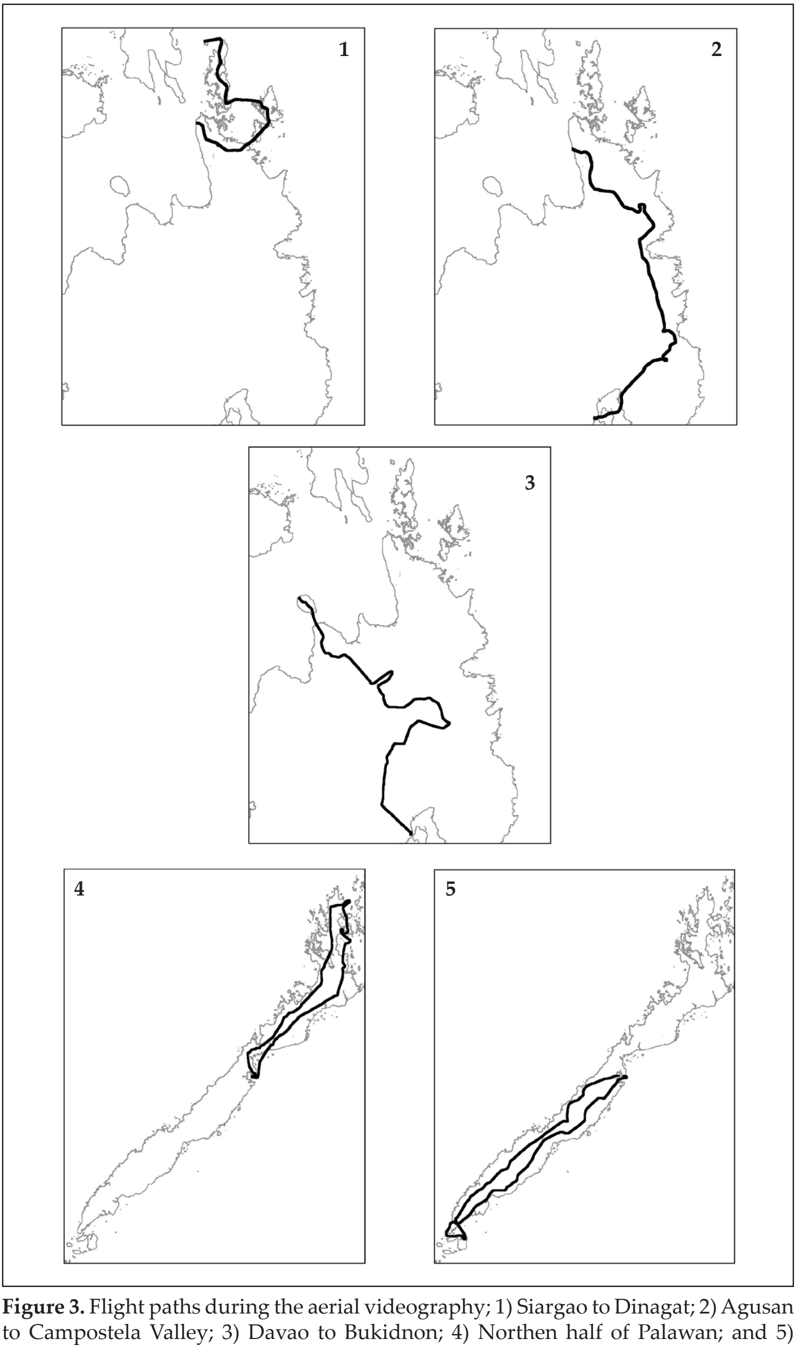

Figure 3. Flight paths during the aerial videography; 1) Siargao to Dinagat; 2) Agusan to Campostela Valley; 3) Davao to Bukidnon; 4) Northen half of Palawan; and 5) Southern half of Palawan

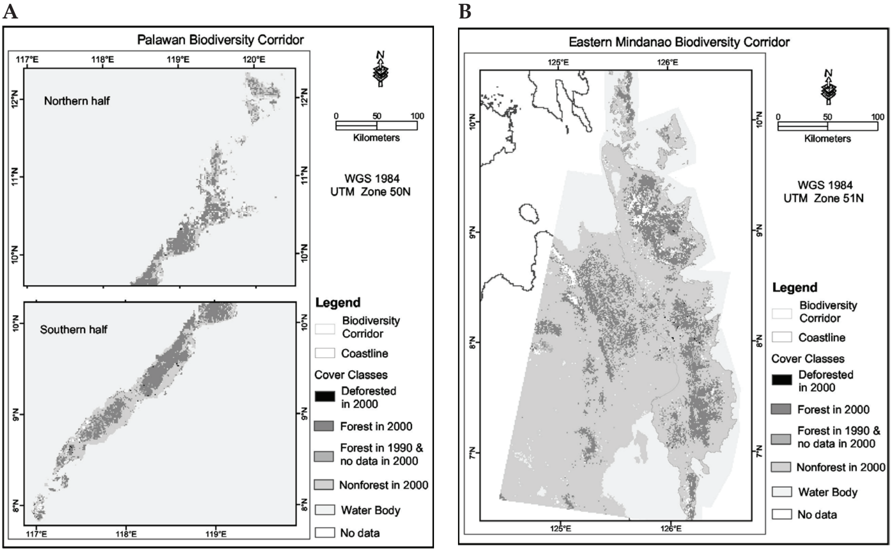

Figure 4. Classification results of Palawan (A) and Eastern Mindanao (B) Biodiversity

which individually map two dates of imagery and then look at the difference between the two maps. The problem with that approach is that errors are typically made in each of the classifications and, therefore, those errors are compounded when the difference is taken between the two. With this two-date classification technique, we found that the rate of deforestation in each of these corridors was quite low (Table 4). In Eastern Mindanao, we observed 20.1 km^2 of forest clearance between 1990-2000, representing only 0.35 percent of total forest cover. In Palawan the amount was 37.5 km^2, representing 0.67 percent of total cover.

Habitat fragmentation

Habitat fragmentation can be studied and analyzed in a number of ways. One way is to study the amount of forest near a non-forest edge. This is known as 'edge' forest and is considered biologically important because a large number of species will only be found away from the forest edge, or in the interior portion of the forest. In our study, we found that both in Palawan and in the Eastern Mindanao corridor, the amount of forest within 500 m of a non-forest edge increased during the period 1990-2000, although the increase was less than 0.5 percent (Table 5).

Table 3. Error Matrix for the classified data versus the ground truth data through aerial surveys in (a) Palawan and (b) Eastern Mindanao

(a) Palawan		Ground truth (aerial photo)				Error of commission	User's accuracy (%)
		Forest	Nonforest	Water	Total		
Classified images (pixel values)	Forest	168	5	0	173	2.89	97
	Nonforest	8	115	0	123	6.50	93
	Water	0	0	33	33	0	100
	Total	176	120	33	329		
		Overall accuracy				96%	
Error of Omission		4.54	4.17	0			
Producers Accuracy (%)		95.46	95.83	100			

(b) Eastern Mindanao		Ground truth (aerial photo)				Error of commission	User's accuracy (%)
		Forest	Nonforest	Water	Total		
Classified images (pixel values)	Forest	140	13	0	153	8.50	92
	Nonforest	73	73	0	146	50.00	50
	Water	0	0	42	42	0	100
	Total	213	86	42	341		
		Overall accuracy				75%	
Error of omission		34.27	15.12	0			
Producers accuracy (%)		65.73	84.88	100			

Table 4. Forest cover and clearance (deforestation) in Eastern Mindanao and Palawan from 1990 to 2000

	Eastern Mindanao				Palawan			
	~1990		~2000		~1990		~2000	
	km^2	%	km^2	%	km^2	%	km^2	%
Forest, known	5,722.3	30.9	5,460.2	29.5	5,606.1	49.2	5,272.3	46.2
Nonforest, known	8,932.1	48.3	12,041.4	65.1	4,795.3	42.1	5,280.3	46.3
Unknown	3,782.4	20.4	908.0	4.9	655.6	5.7	521.5	4.6
Total corridor area (km^2)	18,498.8				11,403.8			
Land area (km^2)	18,194.1				11,351.7			
Forest clearance, observed (km^2)	20.1				37.5			
Forest clearance observed (%)	0.35				0.67			
Average annual forest clearance (%)	0.04				0.07			

Table 5. Proportion of forests that is within one kilometer apart from non-forest

	Eastern Mindanao corridor edge statistics					
	1990		2000		change	
Distance from edge (m)	km^2	% of total	km^2	% of total	km^2	% of total
0-500	3896.6	68.10	3912.5	68.62	-15.9	-0.28
500-1000	900.18	15.73	878.1	15.40	22.08	0.39

	Palawan corridor edge statistics					
	1990		2000		change	
Distance from edge (m)	km^2	% of total	km^2	% of total	km^2	% of total
0-500	2591.3	46.22	2599.5	46.67	-8.2	-0.15
500-1000	1064.2	18.98	970.7	17.43	93.5	1.67

Another way to study fragmentation is to look at average patch size. Decreasing patch sizes are usually an indication of greater fragmentation. In our analysis, we found a surprising result. In Palawan, the percentage of forests in large patches actually increased during 1990-2000 (Table 6). This was due to the loss of several small patches and very little change elsewhere on the island. Because the small patches were lost, the remaining patches were thus larger on average. There was no change in average patch size in Eastern Mindanao.

Forest clearance in key biodiversity areas (KBAs)

In Palawan, 8 of the 13 KBAs are inside the corridor, of which Busuanga Island has the highest area of forest clearance in the last 10 years equivalent to 6.3 km^2. Similarly in Eastern Mindanao, 7 of the 14 KBAs are inside the corridor, of which Bislig has the highest area of forest clearance equivalent to 10.5 km^2 (Table 7).

Conclusions

Remote sensing of forest cover has proven useful for biodiversity monitoring in the Philippines. The two corridors studied total approximately 30,000 km^2 or 3,000,000 hectares, and represent a large portion of the remaining intact forest cover in the Philippines. The production of forest cover and change maps, as well as, the statistical analysis of forest loss and fragmentation provides key facts for policy makers and land managers, in their struggle for biodiversity conservation. Moreover, upcoming talks related to climate change and carbon stocks are likely to further increase the value of such data.

This study is meant to provide a baseline of forest cover and deforestation rates in the Philippines and further monitoring is required to determine if those rates change, as well as, to determine where future pressures on forest habitat are occurring.

The Philippines continues to struggle in terms of mapping, and quantifying forest cover and other landscape features. This study has taken another step towards supplementing biodiversity conservation and the protection of the environment with forest-related information. Although remote sensing is 'expensive' in terms of raw materials, low-cost data access can be provided in a number of ways through partnership and collaboration. Efforts for conservation are neither done overnight nor acted upon by a single body, but it is a collective struggle among the government, private

Table 6. Distribution of forest patches greater than or equal to 100 km^2

Total area of forest patches greater than or equal to 100 km^2 in Palawan			
1990		2000	
km^2	%	km^2	%
4692.8	83.7	4676.6	84.0
Total area of forest patches greater than or equal to 100 km2 in Eastern Mindanao			
1990		2000	
km^2	%	km^2	%
4569.1	79.8	4548.5	79.8

Table 7. Forest statistics of Key Biodiversity Areas (KBA) in (a) Palawan and (b) Eastern Mindanao

(a) Palawan KBA Name	Total area (km^2)	Land area (km^2)	Forest cover 1990 (%)	Forest cover 2000 (%) (km^2)	Forest clearance, observed (%)	Forest clearance, observed
Calauit Islands	34.9	33.0	13.1	13.1	0.0	0.00
Victoria and Anepahan Ranges	163.3	163.3	74.9	69.3	0.4	0.33
Culion Island	393.4	385.8	32.0	30.5	0.1	0.11
Coron Island	73.5	66.3	67.2	67.2	0.0	0.00
El Nido	836.0	375.0	23.9	20.9	2.1	1.07
Malampaya Sound	1658.0	883.1	26.6	26.6	0.0	0.00
Lake Manguao	63.4	57.1	47.8	47.7	0.1	0.27
Dumaran-Araceli	287.7	284.8	4.3	4.3	0.0	0.00
San Vicente-Taytay-Roxas Forests	806.8	806.6	68.6	68.6	0.1	0.02
Puerto Princesa Subterranean River National Park	202.0	192.9	83.4	83.4	0.1	0.04
Cleopatra's Needle	1043.8	1039.1	78.0	77.0	2.2	0.26
Busuanga Island	1638.6	1638.6	92.5	91.4	6.3	0.41
Mt. Mantalingajan	1448.3	1448.2	73.5	69.9	3.2	0.30

(b) Eastern Mindanao KBA Name	Total area (km^2)	Land area (km^2)	Forest cover 1990 (%)	Forest cover 2000 (%) (km^2)	Forest clearance, observed (%)	Forest clearance, observed
Mt. Kambinlio and Mt. Redondo	285.2	280.0	80.6	80.6	0.0	0.00
Siargao Island	631.3	607.0	0.5	0.5	0.0	0.00
Mt. Hilong-hilong	2402.4	2401.8	60.2	59.4	3.7	0.26
Mt. Diwata range	938.0	938.0	51.3	51.3	0.0	0.00
Agusan Marsh	143.7	140.4	25.1	25.3	0.0	0.00
Bislig	1548.3	1546.9	53.2	49.0	10.5	1.28
Mt. Agtuuganon and Mt. Pasian	855.0	854.9	48.1	48.8	0.0	0.00
Mt Kamoalili-Puting Bato	1699.1	1699.1	65.1	67.1	1.1	0.10
Mt. Hamiguitan Range	318.7	318.7	61.8	61.9	0.0	0.00
Mt. Kaluayan-Mt. Kinabalian Complex	1809.8	1809.7	54.7	55.8	0.0	0.00
Mt. Tago range	834.1	834.1	28.6	29.0	0.0	0.00
Mt. Sinaka	17.5	17.5	54.8	68.6	0.0	0.00
Mt. Apo Natural Park	990.9	990.9	32.7	34.9	0.0	0.01
Liguasan Marsh	394.3	360.1	0.0	0.0	0.0	0.00

KBA sites inside the corridor ▨

practitioners and individual citizens, who should be vigilant in protecting forests and the environment.

Conservation International has also mapped forest cover and change in the Sierra Madre Biodiversity corridor in a separate effort in 2003. This was later refined in some of its areas and analyzed using the techniques as reported in this study. For additional information, please contact the authors.

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