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Acknowledgement

I wish to thank...

Abstract

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Acronyms

COE	College of Engineering
UPD	University of the Philippines Diliman

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Measurement Units

B	billion
dB	decibel
ha	hectare
km	kilometer
m	meter
M	million
yr	year

Chapter 1

Introduction

1.1 Background

Forests are complex, functional systems of interacting and interdependent biological, physical, and chemical components, which creates unique combinations of climate, soil, plant and animal species that result in many different forest types around the world (Blanco and Lo, 2012). These ecosystems harbor the vast majority of biological species on Earth (Pan et al., 2013), account for 80% of the Earth's total plant biomass (Kindermann et al., 2008), and store more carbon in biomass and soils than is contained in the atmosphere. Forests not only play an important role in supporting and maintaining ecological systems and cycles, but also provide a broad range of goods and services to humanity, including social and economic benefits in the long term. Among the valuable ecosystem goods and services provided by forests are food, fibre, timber, medicine, clean water, aesthetic and spiritual values, climate regulation, a repository of carbon storage, and mitigation of natural hazards such as floods.

1.2 Remote sensing of Philippine forests

In the Philippines, a nation-archipelago located between the equator and the Tropic of Cancer in Southeast Asia, forests harbor extremely high floral and faunal diversity, and at the same time also serve as home to upland communities that are highly dependent on forest resources. Studies have cited estimates of the extent of forest cover to be ~90% of the 30 M ha total land area of the Philippine islands before the Spanish colonisation in 1521, down to ~70% at the transition of colonial regimes between Spain and America by 1900s, and further reduced to ~60% during the Japanese occupation of the Philippines from 1942 to 1945. During the 20th century, the average deforestation rate in the Philippines was estimated to be 148,000 ha/yr. Recent official forestry statistics in 2015 reported a decline in forest cover from 7.17 M ha in 2003 to 6.84 M ha in 2010 (FMB, 2015). Timber harvesting and agricultural expansion during the Spanish colonisation, followed by rapid and extensive commercial logging in the 20th century were recognised as the main drivers of historical forest loss in the Philippines.

National forest surveys were conducted in the post-1950s period in support of managing the country's forest resources, which employed either ground-based forest surveys or spaceborne remote sensing technology to produce land and forest cover maps. To date, seven national forest surveys using remotely sensed data have been conducted in the Philippines (Table 1.1).

Table 1.1: National forest surveys in the Philippines using remotely sensed data.

Year	Source	Forest Cover (%)	Data Source	Method of Interpretation
1973	Lachowski et al. (1979)	38.0	Landsat	Digital
1974	Bruce (1977)	29.8	Landsat	Visual
1976	Bonita & Revilla (1977)	30.0	Landsat	Visual
1980	Forestry Development Center (1985)	25.9	Landsat	Visual
1987	Swedish Space Corporation (1988)	23.7	SPOT	Visual
2003	National Mapping & Resource Information Authority (2004)	No data	Landsat	Visual
2010	National Mapping & Resource Information Authority (2014)	No data	Landsat, AVNIR	Visual

Note: At the time of its publication, Kummer's (1992b) study enumerated five national forest surveys using remotely sensed data conducted from the 1970s to the 1980s. Additional surveys conducted from 1990s to the present were included to update this list.

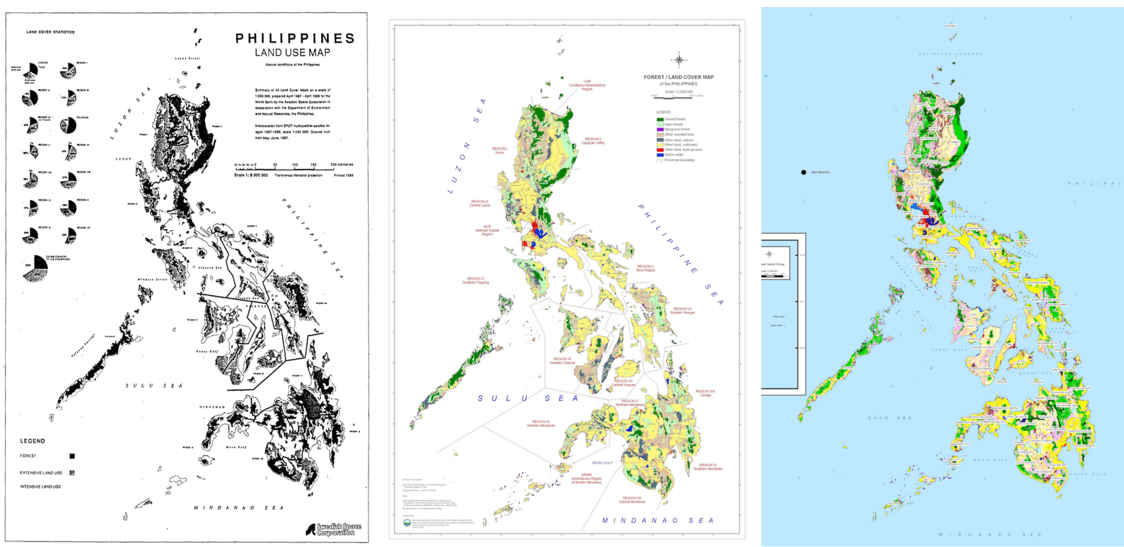
The forest cover maps generated from these past surveys were done mainly by the traditional method of visual or manual interpretation and analysis (except the 1973 maps) using optical remote sensing data, particularly Landsat. While visual interpretation of remotely sensed data is a simple and effective method that can result in excellent spatial information extraction, it is dependent on the extent of knowledge of the analyst regarding the area of study. Also, since the method depends solely on a human analyst it is more subjective, and tends to be tedious and slow compared to automated digital interpretation techniques.

Table 1.2: Forest cover classification systems used in the 1987 and 2003/2010 forest maps.

1987 map	2003/2010 map
Closed canopy, mature >50%	Closed forest, broadleaved
Open canopy, mature <50%	Closed forest, coniferous
Mossy forest	Closed forest, mixed
Pine forest	Open forest, broadleaved
Mangrove forest	Open forest, coniferous
Marshy area and swamp	Open forest, mixed
Submarginal forest	Forest plantation, broadleaved
	Forest plantation, coniferous
	Forest plantation, mangrove (2003 only)
	Mangrove forest

The exclusive use of optical satellite data in these mapping surveys meant that cloud cover was a prevalent concern. In particular, tropical regions such as the Philippines feature persistent cloud cover, which affects data availability and temporal consistency of optical data, thereby preventing regular observations (Myers, 1988). The lack of available optical data due to cloud cover contamination may be one of the major limiting factors in the application of the resulting map products from these forest surveys for periodic, consistent, and wall-to-wall national land and forest cover mapping and monitoring (Fig. 1.1).

Different forest classification systems were also adopted in these forest surveys. For example, the 2003 and 2010 NAMRIA maps employed similar forest classification schemes based on the FAO Global Forest Resources Assessment (GFRA), but these maps differed from the 1987 Swedish Space Corporation (SSC) map that adopted a different system (Table 1.2). The forest definitions used to produce the 1987 map and the 2003/2010 maps were also different from each other. These inconsistencies restrict the direct comparison of these maps and render the results incompatible for historical forest cover change analysis.



(a) (b) (c)

Fig. 1.1: Recent national land cover maps of the Philippines: (a) 1987 SSC; (b) 2003 NAMRIA; (c) 2010 NAMRIA.

Finally, there is little known documentation that exists to report on the methods implemented and levels of accuracy achieved in producing many of the forest cover maps from these surveys, except the 1973 and 1987 maps. Lachowski et al. (1979), for the 1973 Landsat-based maps, described the methods undertaken by the mapping work and mentioned an overall accuracy of 85% to 95% for the classification of forest types, albeit without sufficient detail. For the 1987 SPOT-based maps, SSC Swedish Space Corporation, 1988 described their methods and land cover classification system, but did not quantify the accuracy of the results of their interpretation. Kummer's study had cautioned on the reliability of the 1987 SSC map due to major differences with the results of the 1988 Philippine-German Forest Inventory (Kummer, 1992). Reports for other mapping surveys were either not (or no longer) available or were not easily accessible. Since many of these forest mapping surveys employed visual interpretation techniques implemented by expert analysts, the absence of documentation also affects the replicability of the approaches for future work since the knowledge developed from these surveys were ultimately lost.

Chapter 2

Literature Review

2.1 Lorem ipsum

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Table 2.1: Categories and definitions based on the Global Forest Resources Assessment.

Category	Definition
Forest	Land with tree crown cover (or equivalent stocking level) of more than 10% and area of more than 0.5 ha.
Broadleaved forest	Forest with predominance (more than 75% of tree crown cover) of trees of broadleaved species.

Table 2.1: Categories and definitions based on the Global Forest Resources Assessment.

Category	Definition
Coniferous forest	Forest with predominance (more than 75% of tree crown cover) of trees of coniferous species.
Bamboo/palm formations	Forest on which more than 75% of the crown cover consists of tree species other than coniferous or broadleaved species (e.g. tree-form species of the bamboo, palm and fern families).
Mixed forest	Forest in which neither coniferous, nor broadleaved, nor palms, bamboos, account for more than 75% of the tree crown cover.
Closed forest ($\geq$ 40%)	Natural forest where trees in the various storeys and undergrowth cover 40% of the ground. These formations do not have a continuous dense grass layer. They are either managed or unmanaged forests primary or in an advanced state of reconstitution and may have been logged-over one or more times, having kept their characteristics of forest stands, possibly with modified structure and composition. Typical examples of tropical closed forest formations include tropical rainforest and mangrove forest.
Open forest (10 to $<$40%)	Formations where trees form a discontinuous layer covering 10 to 40% of the ground. This forest usually includes a continuous grass layer allowing grazing activities and the spreading of fires.
Forest plantation	Forest stands established by planting or/and seeding in the process of afforestation or reforestation. They are either of introduced species (all planted stands), or intensively managed stands of indigenous species, which meet all the following criteria: one or two species at plantation, even age class, regular spacing.

2.1.1 Lorem ipsum

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Chapter 3

Methodology

3.1 Lorem ipsum

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$$\sigma^0 = 10 \cdot log_{10}[DN^2] + CF \tag{3.1}$$

Where DN is the digital number and CF is the calibration factor with a value of 83.0 dB for ALOS/PALSAR data.

Chapter 4

Results

4.1 Lorem ipsum

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Chapter 5

Discussion

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Chapter 6

Conclusions and Recommendations

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Appendices

Appendix A

Supplementary: Literature Review

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Appendix B

Supplementary: Methods

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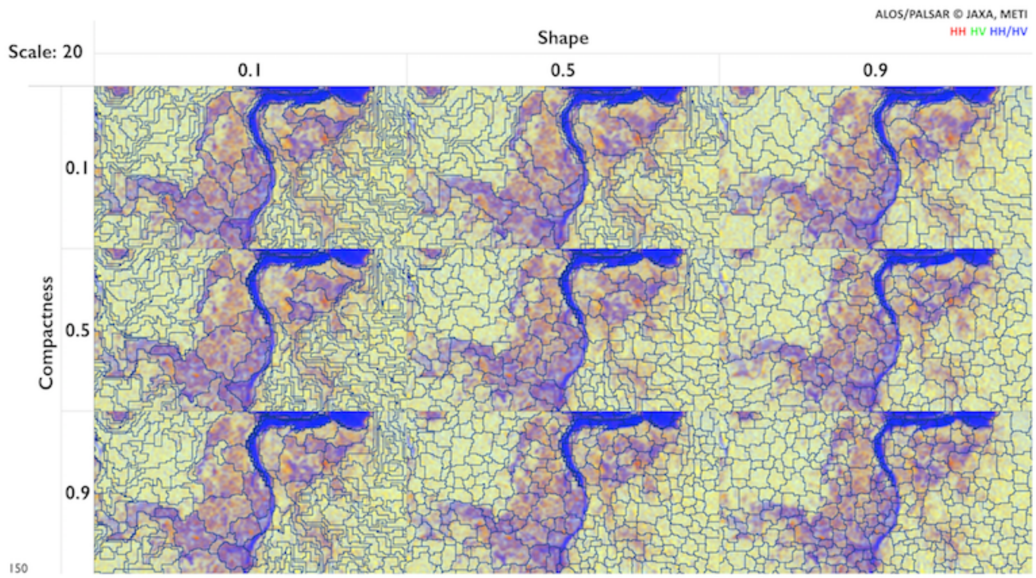

Fig. B.1: Test segmentation images using a scale value of 20 with shape and compactness values set at 0.1, 0.5, and 0.9. Image weights set at 1 for radar and topographic data layers.

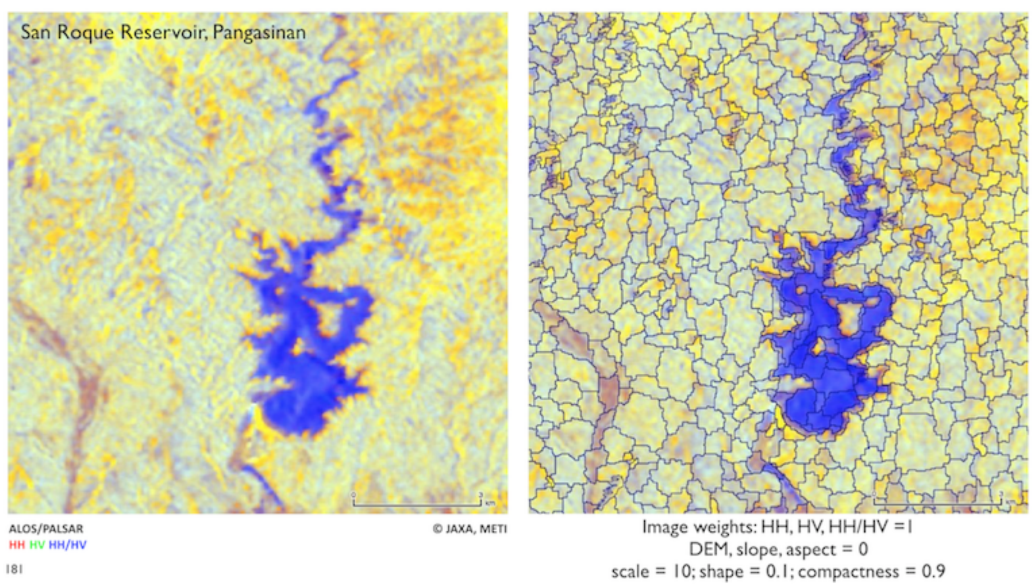

Fig. B.2: Selected segmentation parameters using a scale value of 10, shape value of 0.1, and compactness value at 0.9. Image weights set at 1 for radar data layers and 0 for topographic data layers.

Appendix C

Supplementary: Results

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C.2 Scripts

C.4.1. Sample R script.

```
# This is an R script
```