MANGROVE FOREST EXTENT MAPPING IN SOUTHWESTERN LUZON USING 2015 LANDSAT IMAGERY

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ABSTRACT: Accurate information on mangrove forest extent is essential for both natural resources management and integrated land and sea use planning. In this study, we assessed the spatial distribution of mangrove forests in the provinces of Southwestern Luzon for the year 2015 using publicly available Landsat 8 images. The images were calibrated and atmospherically corrected using the FLAASH model. Support Vector Machine (SVM) was used to classify the images into four classes (i.e., mangroves, terrestrial non-mangroves vegetation, built-up plus bare soil, and cloud cover plus shadows). Results generated the following total areas of mangrove forest cover per province: 42,999 ha in Palawan; 398 ha in Batangas; 3,259 ha in Oriental Mindoro, 1,386 ha in Occidental Mindoro, 137 ha in Cavite and 10,570 ha in Quezon. In general, the mangrove areal estimates of our study were comparable to previous remote sensing studies conducted in the Philippines. Although there are some discrepancies with the results, the overall accuracy of above 95% and kappa coefficient of above 0.9 indicate that the spatial distribution of mangroves was accurate. The results of this study are considered important contributions to rapid ecological assessment of mangroves, and can aid in mangrove conservation and management.

1. Introduction

Mangroves are trees and shrubs that are uniquely adapted to marine and brackish waters (Duke et al. 1998). Similar to coral reefs and rainforests, they are highly productive, complex and diverse coastal ecosystems. Healthy mangroves form dense stands along the coastal fringes and estuaries within the intertidal zones of the tropical and subtropical regions worldwide (UNEP 2014). Although mangroves can exist in isolation, they typically occur with other associated coastal ecosystems (i.e. coral reefs, seagrass beds, algal beds, mud flats, and sand flats; Nagelkerken, 2009) and their association with these ecosystems enhance important ecological functions such as fisheries and biodiversity (Ogden 2014).

Mangroves are often perceived as nothing more than muddy wastelands, but in fact, they offer a wide range of economic, social, and environmental benefits often referred to as ecosystem goods and services (MEA, 2005). Mangrove stands provide security from natural disasters as they serve as natural barriers along the land-sea interface. Moreover, the growth of mangroves at the land-sea interface promotes sediment trapping from both land and sea and not only prevents soil erosion but also facilitates soil accretion. In archipelagic countries where most of the population lives within coastal communities, such as the Philippines, mangroves are mainly utilized as a source of fuel wood and food. Mangrove fish and shellfish provide the main source of protein for many coastal communities, in addition to livelihood opportunities they bring. The association of multiple coastal habitats also affects species diversity, with increased number of species when adjacent mangrove habitat is present due to their nursery function (Nagelkerken et al. 2009, Mumby et al. 2004). A large number of commercially important fisheries such as shrimp, crabs, and fishes (e.g., snapper, mullet, wrasse, parrotfish, sharks, and rays) utilizes mangroves during at least a part of their life cycle, usually during the juvenile phase to maximize periods of development, i.e. consumption of food items that enhance juvenile growth (Nakamura et al. 2003). Moreover, some species show diel movements from adjacent ecosystems into the mangroves at high tide to feed on mangrove-associated food items (Honda et al. 2013), thus promoting growth and production in nearby associated ecosystems.

Despite its ecological importance, mangroves suffer the earliest and greatest damages among major marine ecosystems. The long history of conversion to aquaculture ponds have caused an estimated lost of 20% (3.6 million ha) of mangrove between 1980 and 2005 globally (FAO 2007; Primavera 2000), and is expected to continue (UNEP 2014). Overexploitation of mangrove resources for large scale industrial harvesting and small-scale collection for fuel wood and coal also caused significant declines in mangrove cover. Since mangroves occupy relatively flat coastal areas, the high demand for coastal development in these areas has also caused major loss in mangrove cover over the decades. In the Philippines, the largest decline was recorded from 1951 to 1988 where around half of the 279,000 ha of mangroves were lost due to development of aquaculture ponds (Primavera 2000). In 1994, only 120,500 ha of mangroves have been recorded and is continuously showing traces of overexploitation and other threats.

A vital part of mangrove management is to identify the spatial forest cover, key regions to protect, and possible sources of threats. Remote sensing has been a popular tool used in natural resources monitoring. It has been widely used in monitoring land use, tracking historical changes in forest cover, and habitat mapping. Although several studies have been conducted to provide best estimates of spatial mangrove extent, a consistent methodology is still lacking (Long et al. 2013). In the Philippines, several approaches have been used to provide accurate information on mangrove extent. Long and Giri (2011) provided a nationwide estimate of the mangrove forest cover using Iterative Self-Organizing Data Analysis Techniques (ISODATA) classification method. In 2013, a similar study has also been conducted by Long et al. using a different classification method, Support Vector Machine (SVM). Localized change detection of mangrove forest has also been conducted such as in the city of Puerto Princesa, Palawan (Pagkalinawan & Ramos, in prep).

This study aims to quantify the current areal extent of mangrove forest in the Southwestern part of Luzon, Philippines by detecting the spatial distribution of the mangroves through the analyses of satellite images acquired in the months of 2015.

2. Methodology

2.1. Study area

The study focused on the Southwestern provinces of Luzon: Cavite, Batangas, Quezon, Occidental and Oriental Mindoro and Palawan (**Fig. 14**).

Palawan is located in the westernmost part of the Philippines with coordinates 09°30'N and 118°30'E. It is known as the country's "last ecological frontier" supporting a repository of unique and diverse fauna and flora (Sandalo & Baltazar 1997). Previous studies reported varied estimates of mangrove forest cover in Palawan, from a value of 37,432 ha (Philippine Clearing House Mechanism for Biodiversity, 2009); 42,500 ha (CI-Philippines 2011) to an area of 56,660 ha (Long & Giri 2011). Batangas, Occidental Mindoro and Oriental Mindoro is located northeast of Palawan. These provinces border the Verde Island Passage, the "center of the center of marine biodiversity of the world" and the "center of the center of marine shorefish biodiversity" (Carpenter & Springer 2005). It houses diverse species of corals, algae, crustaceans, mollusks, marine reptiles, marine mammals, mangroves and fishes, including some globally threatened fish species (Carpenter & Springer 2005). A study conducted by CI through Coral Triangle Support Program (CTSP) reported a total of 2,583 ha of mangroves (circa 2010) and 2,317 ha (circa 1990) throughout the Verde Island Passage.

Like the island of Palawan, Puerto Galera in Oriental Mindoro was declared as a "Man and Biosphere Reserve" by UNESCO. There are 20 marine protected areas in Oriental Mindoro that include a marine turtle reserve and a mangrove forest reserve. In 2010, there is an estimate of 148 ha of mangroves in Occidental Mindoro (including Lubang Island Group) and 1,770 ha in Oriental Mindoro

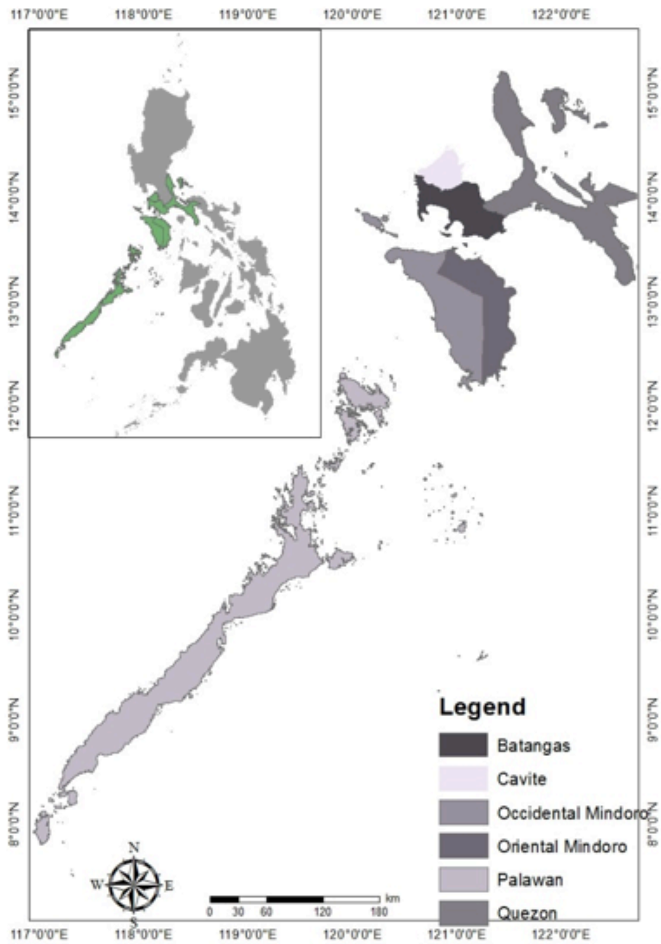

Figure 14. Study sites in Southwestern Luzon (Palawan, Batangas, Cavite, Quezon, Oriental Mindoro and Occidental Mindoro) Philippines for mangrove mapping.

(CI-Philippines, 2011). These estimates did not include the whole province, but only those within the coverage of VIP (northern part of Mindoro).

Cavite is situated near central Luzon at 14°28'N, 120°55'E. It is bounded by the provinces of Batangas and Laguna to the south, Metro Manila to the north and Manila Bay to the west. Cavite is known as one of the major producers of oysters and mussels. Fishers are also engage in prawn and milkfish production. Despite the wonderful beaches along the coast of the province, Cavite is also bounded by Manila Bay, a now polluted bay suffering from industrial and human wastes.

Quezon province is one of the largest provinces of Luzon located east of Manila and bordered by the provinces of Aurora to the north, Camarines Norte and Camarines Sur to the east, and Bulacan, Rizal, Laguna and Batangas to the west. The province is also one of the provinces in the Philippines with the most extensive coast extending up to 1,468 km bounded by Lamon Bay in the pacific side and Tayabas Bay, Sibuyan Bay and Ragay Gulf in the south.

2.2. Data

Satellite images taken by Landsat Data Continuity Mission were downloaded through the USGS Global Visualization Viewer website and served as our primary source of data. Scenes with minimum cloud cover for selected months in 2015 were obtained. The Landsat 8 satellite with Operational Land Imager (OLI) and Thermal Infrared Sensors (TIRS) was used in capturing the data for each month. Secondary data, such as existing mangrove maps and shape files of study sites, were obtained for comparison of results, mainly from the study of Long and Giri (2011).

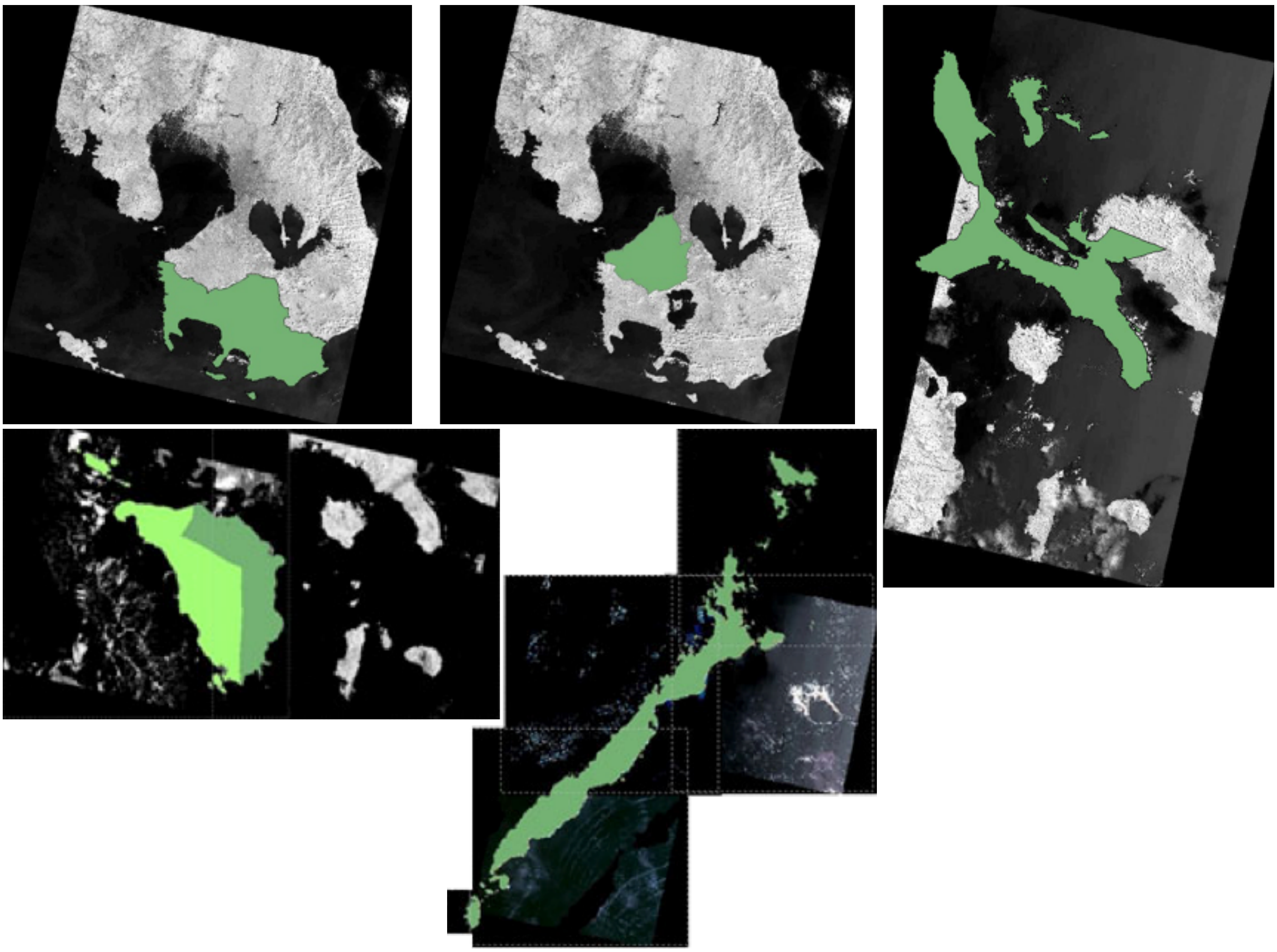

Figure 15. Landsat 8 Images downloaded for mapping mangrove forest extent in Southwestern Luzon, Philippines for year 2015.

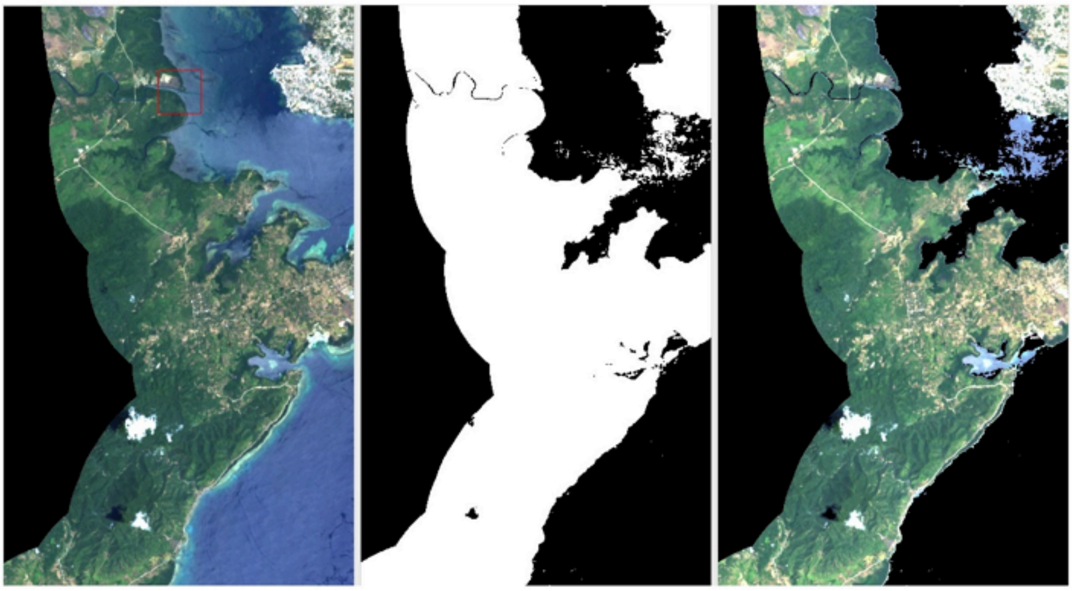

Figure 16. Mask Buffer Creation. A buffer of 4,000 m from the shore was applied to the pre-processed Landsat image (A). A water mask was then created (B) using Band 5 (NIR), and applied to generate an image ready for SVM classification (C). Image is a subset of Palawan scene 3.

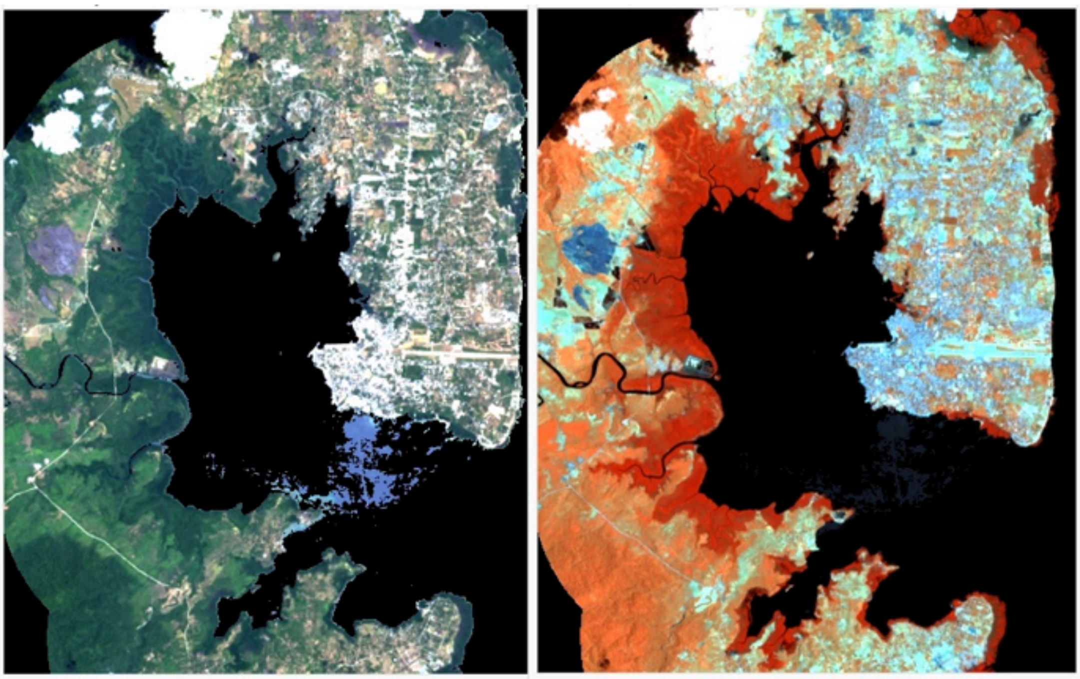

Figure 17. Appearance of mangrove forest from true color (left) to false color composite (right) of the masked Landsat imagery (subset showing Puerto Princesa, Palawan).

2.3. Methods

Pre-processing and processing techniques were applied to the downloaded satellite images to extract the mangrove forest extent. The Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes (FLAASH) model was applied to atmospherically correct the data using the ENVI classic software. Support Vector Machine (SVM) was then used to classify the images to four classes: (1) Mangroves, (2) Terrestrial non-Mangroves vegetation, (3) Built-up plus Bare soil and (4) Cloud Cover plus Shadows. Maps were created showing the location of the mangrove forest extent for each study site for the year 2015.

2.3.1. Pre-Processing and Calibration

Satellite images were calibrated by converting their DN values to radiance. This step requires the data for the LMin and LMax spectral radiance scaling factors specific to the downloaded scenes. The tool used is 'Landsat Calibration' under the Envi calibration utilities.

The FLAASH model was used to correct for the atmospheric effects in the images. This tool corrects wavelengths in the visible through near-infrared and shortwave infrared regions. The calibrated multiband image was converted to band-interleave-by-line (BIL) and used as the input to the FLAASH tool, with a scaled reflectance as the final output.

2.3.2 Masking
Observed land and water areas that can be easily identified as non-mangroves habitats were masked off. Since mangroves thrive only in intertidal zones, a buffer mask measuring 4,000 meter from the shore were created (**Fig. 16**). Areas beyond the 4,000 meter region are excluded in mangroves classification to avoid confusion with other inland vegetation with similar spectral signature. Water was also masked off by visual interpretation of color composites of Landsat ETM bands 4, 5 and 7; and by using either Band 5 (near infrared) or Band 6 (SWIR) for selecting the minimum and maximum value for building the mask.

2.3.3 Mangroves visual interpretation and classification
Mangrove forest cover was visualized using a false color composite of one near infrared band and two shortwave infrared bands (Bands 5-6-7). This composite image highlighted the mangrove vegetation with a bright orange color (**Fig. 17**) which aided in the selection of regions of interests (ROI). A minimum of 150 ROI was selected for the mangroves and other classes (terrestrial non-mangroves vegetation, built-up + bare soil and clouds + shadows). The supervised classification method SVM was applied on the calibrated and masked reflectance file using ENVI.

2.3.4 Mangrove area and post classification comparison
The area of the extracted mangroves was computed using ArcGIS. The area of mapped mangrove cover extent was compared to secondary sources. Accuracy assessment was conducted by generating random points within the buffer zone and cross validating each point with secondary data and Google Earth images. Mangrove forest cover maps of study sites for 2015 were then created using ArcGIS layout tools.

3. Results and discussion

3.1. Land cover classification

A mask was applied prior to classification to exclude water bodies during the classification process. A buffer was then used to limit the classification to within 4 km from the coast since mangroves are only found within this range. Four classes were used in the classification: mangroves, terrestrial non-mangroves, built-up + bare soil and clouds + shadows.

3.2. Mangrove extent and status

This study provides information on the current status of mangrove habitats in Southwestern Luzon provinces. Among sites, Palawan has the largest total mangrove forest extent of 43,000 ha followed by Quezon province at around 14,600 ha. However, in terms of mangrove cover per length of coastline, Palawan is only second to Quezon province with mangrove cover of 8.2 ha/km and 9.9 ha/km, respectively. On the other hand, Cavite has the least mangrove cover (137.4 ha) followed by Batangas (397.6 ha).

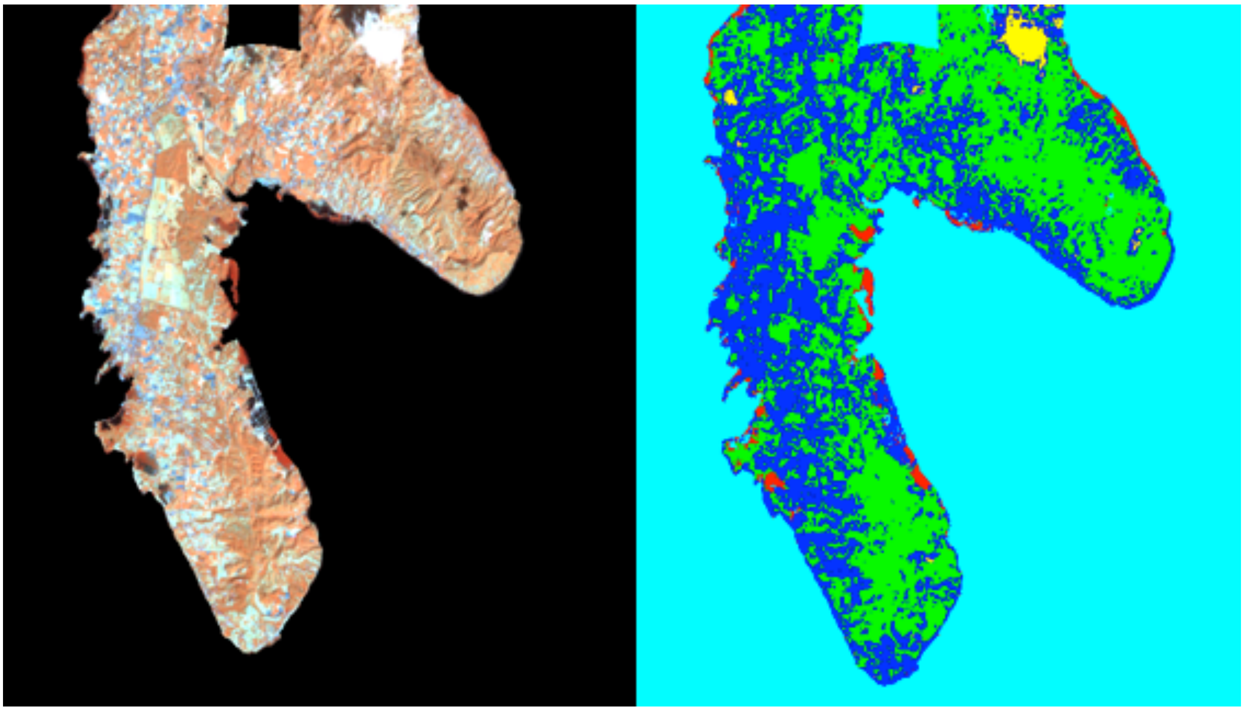

Figure 18. False color composite (left) and SVM classification result (right) in Verde Island Passage subset. (Red: mangroves, Blue: built-up and bare soil, Green: other land vegetation, Yellow: clouds and shadows).

Table 17. Status of Mangroves in Southern Luzon study sites based on current and previous estimates.

Site	Coastline	Areal Extent (ha)		Mangrove Cover per Length of Coastline (ha per km)	
		Long et al. 2011	This Study (2015)	Long et al. 2011	This Study (2015)
Quezon	1,468	10,570	14,620	7.2	9.9
Cavite	96	29.23	137.4	0.3	1.4
Batangas	422.5	503.3	397.6	1.2	0.9
Palawan	5,255	56,660	43,000	10.8	8.2
Oriental Mindoro	438.4	2,227	3,260	5.1	7.4
Occidental Mindoro	690.1	1,041	1,386	1.5	2

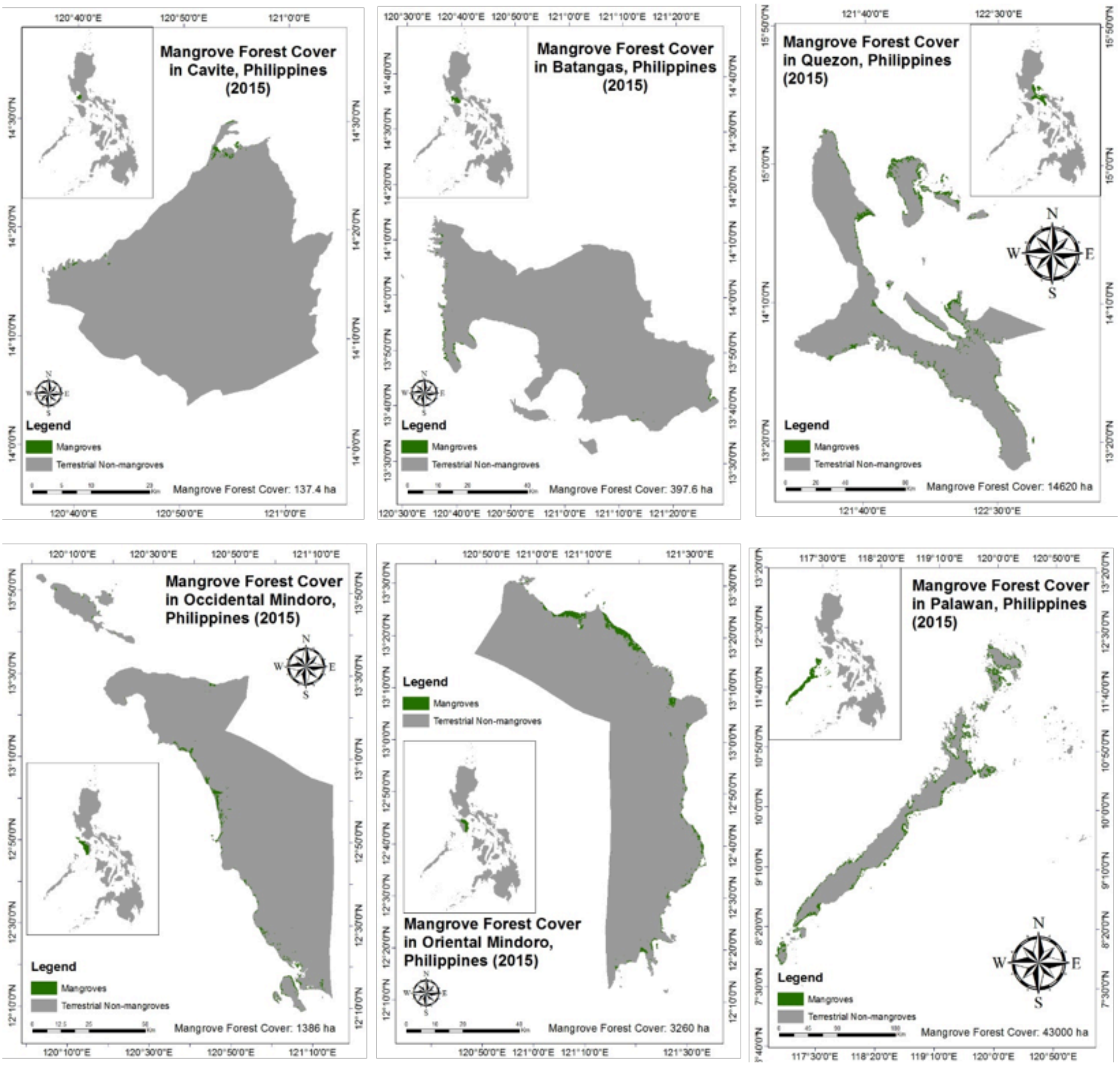

Figure 19. Mangrove forest cover maps of Southwestern Luzon Provinces in the Philippines.

In terms of mangrove cover per length of coastline, Cavite has greater cover than Batangas at 1.4 ha/km and 0.9 ha/km, respectively (**Table 17**).

In Palawan, mangroves were found throughout the coastal areas of the island. However, the eastern part has more continuous mangroves stands such as the mangrove forest from Puerto Princesa extending up to Brooke's Point. Remote islands such as Coron, Culion, Araceli and Balabac were all bordered by mangrove forests. In Oriental Mindoro, mangroves were concentrated on the northern part of the province within the towns of Calapan, Naujan, and Pola. There are thin stands along the coast of Pinamalayan extending up to Mansalay. The mangrove cover in Occidental Mindoro is less compared to Oriental Mindoro, with dense stands present only in Mamburao, Santa Cruz and northern Sablayan.

In Batangas, majority of the mangrove forests are found in Calatagan and San Juan. Barangay Quilitisan, Calatagan, has two islets declared as the Calatagan Mangrove Forest Conservation Park (CMFCP). The CMFCP is a marine protected area co-managed by the Barangay Local Government Unit and by a local people's organization called Talimusak, an organization of local fishers. On the eastern part of the province, San Juan, mangrove rehabilitation has been used to promote tourism. The movement not only enhances tourism, but also increases the awareness of locals and tourists about the importance and benefits of mangroves.

Mangroves are distributed along the lengthy coast of Quezon province. Thick mangrove stands are also notable in the northern coast of Calauag, southern coast of Infanta, and in the island of Polillo. Quezon is also known as the Philippines' "mangrove haven" due to the high survival rate of mangrove propagules planted in the area in 2012. The success of mangrove transplantation in Quezon was attributed to the coastal community's cooperation and awareness on the importance of mangrove forests.

In a study conducted by the Department of Environment and Natural Resources (ICM and PG-ENRO) in 2005, there are only 23.8 ha of mangroves in Cavite located mostly in the municipalities of Kawit and Ternate. The decline in mangrove forest cover is mainly due to conversion to aquaculture ponds, salt-beds and built-up areas. However, due to a joint awareness program and mangrove planting projects conducted by the coastal municipalities in the province, mangroves started to increase to 32.69 ha by 2007, and continue to increase until 2015.

In comparison with the mangrove estimates of Long et al. in 2011, the mangrove areas in Quezon, Cavite, Oriental and Occidental Mindoro increased from 2011 to 2015. The increase in cover can be attributed to the conservation efforts done in the area. On the other hand, there is a decline in mangrove cover in Palawan and Batangas, which may be due to the effects of typhoons. Although the differences in mangrove cover estimates may also be due to the differences in method of classification used, accuracy above 95% and kappa value above 0.9 indicate that our results are comparable with previous estimates.

4. Conclusions and recommendation

Using SVM classification algorithm, the current estimate of the mangrove forest extent in Southwestern Luzon was obtained. Based on the analysis of remotely sensed satellite images, all provinces have thin to dense mangroves cover. Palawan has the largest mangroves areal extent while Cavite has the least. However, based on the mangrove cover per length of coastline ratio, Quezon has the greatest mangrove cover per length of coastline while Batangas has the least. According to the LGU and Department of Environment and Natural Resources (DENR) officials from the study sites, factors inducing the changes in their respective mangroves forests include conversion to fishponds and other resource uses, zero or failed reforestation, pollution and over harvesting; and natural causes such as strong typhoons, sedimentation and climate change-related events (2nd State of the Mangroves Summit LGU Reports, 2015). Despite the challenge in providing mangrove cover estimates on a provincial level, our method proved to be effective for extensive and quick estimates using the limited resources available. However, ground truth validation, which the study lacks, can potentially enhance the result of the mangrove cover estimates. The results of our study provide important information that may improve mangrove monitoring strategies in protected areas. Moreover, it reports the most recent estimate of mangroves that will help the local government to assess the status of their management and conservation efforts in protecting their mangrove forests.

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