ASSESSING LAND COVER/LAND USE CHANGE IN A SMALL ISLAND PROTECTED AREA THROUGH GOOGLE EARTH ENGINE: THE CASE OF BATANES

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ABSTRACT: This study explores the use of Google Earth Engine in performing satellite data analysis of land cover/land use change (LCLUC) on an island protected area before and after enactment. The study area is Batanes, the northernmost province of the Philippines that was declared as a protected area on 2001 through Republic Act (RA) 8991. Landsat images/composites from 1989, 1997, 2000, 2007, 2010, and 2016 are used to determine land use/land cover changes in the islands of Batan, Sabtang, and Itbayat. Image preprocessing, normalization, and Support Vector Machine (SVM) classification are performed in Google Earth Engine. Overall accuracies were 86.97% (2016), 88.07% (2010), 84.47% (2007), 82.97% (2000), 87.98% (1993), and 87.63% (1989). Poor classification on agriculture, barren, and built-up were observed due to a high degree of spectral mixing. In particular, agriculture plots bordered by hedgerows consisting of reeds or trees and an indigenous practice of farm-to-fallow every 3-5 years impairs accurate classification of agriculture and grasslands. After separating unprotected lands, the results show an increasing trend in forest cover for the whole province. Other than RA 8991 alone, several laws enacted since 1988 has decreased conversion threats. Furthermore, indigenous agricultural practices and self-sufficiency helped reduce further anthropogenic disturbance. Analysis per island indicates Batan has an upward trend in forest cover while those in Sabtang and Itbayat are relatively stable. Also, a lower portion of the lands in Itbayat is dedicated to conservation due to a conflict with ancestral domain claims. Inspection of protected and unprotected maps was observed to include agricultural plots thus potentially classifying disturbed areas as protected. The province will benefit from high-resolution imagery classification and a better map separating protected and unprotected lands. Overall, this study presents a preliminary evaluation of LCLUC in the province and provides valuable information for managers to assist conservation efforts in the province.

1. INTRODUCTION

Islands are geographically isolated regions that account around 1/6 of the Earth's surface (Paulay, 1994). Compared to continental land masses, islands are particularly sensitive to variability due to its limited resource base (Briguglio, 1995). The resource base can shift through natural and anthropogenic disturbances, triggering land cover/land use change (LCLUC). Fast-paced changes are experienced as island communities tend to entirely depend on local resources for ecosystem services (Pelling & Uitto, 2001). Fortunately, LCLUC in islands are self-contained, but mitigation or adaptation measures should be explored locally.

Declaring islands as protected areas help preserve remaining ecosystems and resource bases (Calado et al., 2014). However, protected areas are methods of conservation that typically limits individual access to critical locations; enacting rules that restrict access conflicts with anthropogenic use of the land. Protected areas are good conservation procedures that can enhance ecological and ecosystem services (DeFries, Hansen, Turner, Reid, & Liu, 2007; Geldmann et al., 2013) but are detrimental if the benefit does not extend to its intended purpose. Remote sensing can aid efforts to produce results that will help understand LCLUC in protected areas (Nagendra et al., 2013). High spatial and temporal resolution satellites allow observation of some protected areas before and after gazettement. Underlying LCLUC conditions can be observed from local to national levels up to real-time assessments that can serve as baselines or warning systems for protected area managers (Nagendra et al., 2013).

Protected areas in the Philippines are part of the National Integrated Protected Areas System (NIPAS) and constitute more than 240 sites consisting of land parcels, marine, and island protected areas covering 5.45 million hectares or 14.2% of the total area of the country (DENR-BMB, 2014). NIPAS aims to promote biodiversity conservation yet NIPAS has been fraught with policy inconsistency and management problems (La Viña, Kho, & Caleda, 2010). This problem is reflected by the observations of Mallari, Collar, McGowan, & Marsden (2016) where the country's conservation targets are delayed. Furthermore, Apan, Suarez, Maraseni, & Castillo (2017) reveals that protected areas in the country, with respect to forest cover, are only protected within itself and is consistent to the findings of DeFries et al. (2005), Joppa et al. (2008), and Nagendra (2008) in other protected areas, suggesting disconnection of the area to the wider landscape. Whether NIPAS influenced the process of LCLUC is unexplored.

Batanes is the northernmost province of the Philippines. It is home to the Ivatans, a resilient group of indigenous people known to practice sustainable resource use in agriculture and fisheries (de Guzman, Zamora, Talubo, & Hostallero, 2014; Mangahas, 2010). The province is a known tourist spot for its natural scenery and the cultural heritage of the Ivatans. Republic Act (RA) 8991 safeguards the province as a protected area. Its flora and fauna, however, are limited and particularly vulnerable to anthropogenic encroachment the could be leading to decrease of species habitats. As of writing, literature is lacking on the impact of RA 8991 in the province. The knowledge gap presents an opportunity to discover the impact of policy to the protected area and to understand LCLUC in islands as commonly found in the Philippine archipelago.

The main objectives of the study are to examine LCLUC before and after gazettement of a protected area and explore the capabilities of GEE for remote sensing analysis. Specifically, LCLUC analysis will be performed on protected lands in the islands of Batan, Sabtang, and Itbayat. Estimates of the area of the lands that are changing between protected and unprotected lands will provide insights on the impact of LCLUC before and after RA 8991.

2. THE STUDY AREA

Batanes is the northernmost province of the Philippines (Figure 1). Three are inhabited: Batan, Sabtang, and Itbayat. The rest are uninhabited: Dekey, Ivujos, Dinem, Disiayan (Siayan), Ditarem (Matarem), Misanga, and Dimavulis (Mavudis). The total land area is estimated to be 219.01 km^2 while the sea area is 4500 square kilometers. Around 31.5 km^2 of land is situated in the uninhabited islands. The province is composed of six municipalities with 29 barangays. Sabtang and Itbayat are island municipalities while Basco, Mahatao, Ivana, and Uyugan are all located in Batan. As of 2015, the population is 17246 and majority of the population are situated in Basco (PSA, 2016). The climate of the province is semi-tropical; the province lies near the upper boundary of the Tropic of Cancer. The climate is characterized by unpredictable rainfall distributed throughout the year. A summer-like season (locally known as *rayun*) lasts from March to May while a winter-like season (locally known as *amian*) is experienced from November to February (Mangahas, 1996). The average temperature for the year is 26°C while the average monthly temperature ranges from 22°C (January) to 28.5°C (July). August is the rainiest month and the driest month is April. The average days of rainfall are 183. The typhoon season is between June and October and an average of six typhoons hitting the province each year (Blolong & others, 1996). Geographically, the province is mainly hills, mountains, and grasslands that comprise about 93% of the land area with limited agriculture and settlement potential (Bastillo, n.d.; de Guzman et al., 2014).

Although natural resources are limited, the local indigenous group (Ivatans) are self-sufficient at the household level in agriculture and fisheries (de Guzman, Zamora, Talubo, & Hostallero, 2014; Mangahas, 2010). A local agriculture practice involve a crop cycle period timed with the climate where tilled land will be left for a period to regenerate (de Guzman, Zamora, Talubo, & Hostallero, 2014). During this time, the land is used to farm livestock. Agriculture plots are commonly rectangular in shape and bordered by hedgerows made from reeds *(Miscanthus spp.*) or trees (de Guzman, Zamora, Talubo, & Hostallero, 2014).

The province is under the National Integrated Protected Area System (NIPAS); Batanes is formally recognized as a protected area under Republic Act 8991 signed on January 5, 2001. The history of Batanes as a protected area, however, dates back to 1994. Batanes was previously cited as a protected area through the Integrated Protected Area System (IPAS) and Presidential Proclamation No. 335, s. 1994. RA 8991 also recognizes the province as part of the Indigenous Peoples Rights Act (IPRA) of the National Commission on Indigenous Peoples (NCIP), allowing the traditional use of land together with conservation objectives. Only Itbayat Island has a Certificate of Ancestral Domain. Additionally, a logging moratorium is in place in the province since 1988 (Bugayong, 2006).

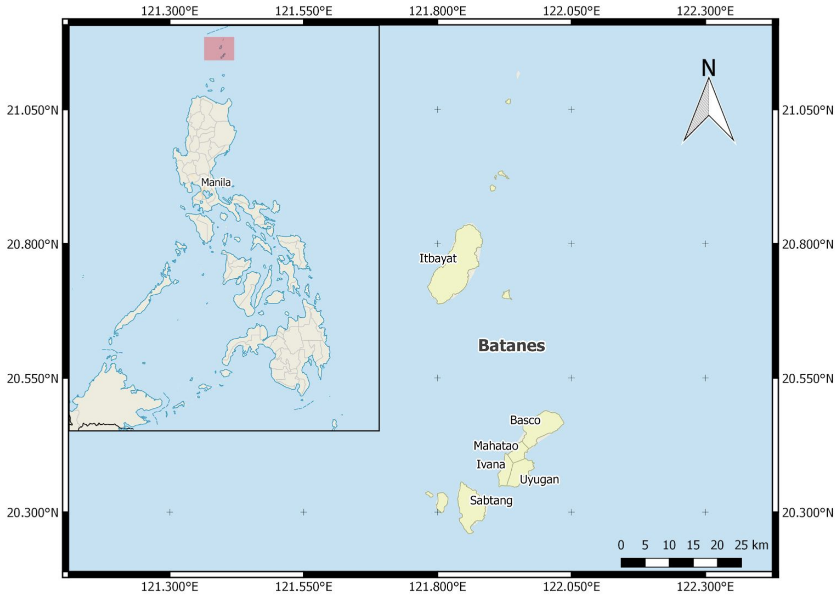

Figure 1. Map of the Batanes Protected Landscape and Seascape and its location in the Philippines. The total land area of the province is 219.01 km^2, Batan is 95.18 km^2, Sabtang is 40.70 km^2, and Itbayat is 83.13 km^2. Map data source: Natural Earth.

3. METHODOLOGY

3.1 Data Acquisition

Images and composites of the years 1989, 1993, 2001, 2007, 2010, and 2016 from Landsat 5 TM and Landsat 8 OLI/TIRS are used as input. Only the 1989 and 2017 are single images due to sufficient cloud-free conditions. All are orthorectified and georeferenced within 0.5 pixels (Townshend, Gurney, McManus, & Justice, 1992) and, in the Landsat 5 images, uploaded to Google Earth Engine. Conversion to TOA Reflectance was performed using procedures detailed in the data users handbook (USGS, 2011). Clouds were manually masked.

A digital map of the study area separating protected lands (Protection and Forested Land) and unprotected lands (Alienable and Disposable, Built-up Area) was obtained from the Provincial Planning and Development Office (PPDO) in the Provincial Office of Batanes. While “Protection Land” is a no-take zone, “Forest Land” takes the definition of a “National Park”. According to RA 7586 or the National Integrated Protected Area System (NIPAS) Act, a national park is “a forest reservation essentially of natural wilderness character which has been withdrawn from settlement, occupancy or any form of exploitation except in conformity with approved management plan and set aside as such exclusively to conserve the area or preserve the scenery, the natural and historic objects, wild animals and plants therein and to provide enjoyment of these features in such areas”.

3.2 Relative Radiometric Normalization

Relative Radiometric Normalization was performed on all Landsat images with the goal of reducing inter-image variability induced by seasonal and sensor attributes (Davies et al., 2016). The TOA reflectance image from 2000-04-05 was used as the base image for correction. Wavelength-dependent linear regression was utilized as the normalization method. Since the resulting images are normalized to the base image, the requirement for atmospheric correction can be disregarded (Song et al. 2001). Atmospheric properties in the study area for atmospheric correction is not available, and Landsat surface reflectance products can be erroneous near or at coastal regions (Vermote et al., 2016).

The selected method requires pseudo-invariant features (PIF) as the dataset. PIFs are areas in the image that are spectrally stable throughout the study period. A semi-automatic PIF selection technique was implemented in GEE that determines PIFs by calculating the standard deviation per pixel per band for all images. Pixels that deviate by at least 5% of the mean were flagged as PIFs. Only the RGB and NIR bands are used for normalization. Root mean square error (RMSE) was calculated to assess the performance of normalization (Yang & Lo, 2000). A 0.02 RMSE is used as a benchmark for successful normalization (Moran et al., 1992).

3.3 Classification and Change Detection

Support vector machine (SVM) classification was used in this study. SVM is a classification technique that finds an optimal hyperplane between data into a high-dimension space through calculation of the least distance between samples, called support vectors, on the edge of the class space. A kernel is implemented to transform the hyperplane non-linearly. The kernel used in the study is the Radial Basis Function (Hsu, Chang, & Lin, 2016). Five land cover/land use classes are used: Agriculture, Barren, Inland Water, Built-up, Forest, and Grassland. Bare soil was classified as "Barren" as the feature corresponds to agriculture plots in the study area. A grid-search function was performed in GEE to find the best parameters. The RGB and NIR bands along with a NDVI and SRTM 30m DEM were used as parameters for classification. Post-classification smoothing cleanup was performed by applying a 3x3 square kernel using a majority (mode) filter.

Training data are selected through careful examination of high-resolution Google Earth imagery, field knowledge, and the selected Landsat images. Since SVM is utilized, the training data can be manually selected and should incorporate pixels that will represent the best support vectors (Foody and Mathur, 2006). Training sets are selected by visual examination of stable pixels per class in each island. Additionally, the Landsat images are inspected with high-resolution images from Google Earth.

Validation was performed by cross-checking the classified map to reference land cover maps from the Bureau of Soils and Water Management (BSWM) for the year 1988 and the National Mapping and Resource Information Agency (NAMRIA) for 2003, 2010, and 2015. Validation of some categories was not possible due to lack of consistent classes. Accuracy is, therefore, inspected as a function of correct classification of stable areas over time as observed in the reference. For validation, overlaps of similar classes within two or all land cover maps are used as validation areas. Since the selected areas should be stable throughout the period, the validation areas are used on all images.

Post-classification change detection is performed to determine the trajectory of classes in the study period. In GEE, a conditional statement function was implemented to generate a change map. If a condition is met (i.e. grassland is converted to agriculture), a value unique to the change is set. For statistics, the following changes were considered: Forest to Agriculture, Forest to Grassland, Grassland to Agriculture, Agriculture to Grassland, Agriculture to Forest, Grassland to Forest. The count was converted to area by multiplying to the estimated area of one Landsat pixel (900 square meters or 0.0009 square kilometers).

4. RESULTS

The RMSE values from the image normalization method yielded values below 0.02 except the NIR band which reached up to 0.023 RMSE for the 1989 image. However, the NIR band is critical for classifying vegetation and generating NDVI and was retained for all bands. A classification test without the NIR band yielded poor results. Due to clouds, 15.67 km^2 were not included in the analysis (Figure 2).

Overall accuracies of the images were 86.97% (2016), 88.07% (2010), 84.47% (2007), 82.97% (2000), 87.98% (1993), and 87.63% (1989). High producer and user accuracies are obtained for forest and grassland categories (>79%). However, inspection of user and producer accuracies yielded very poor results (4-70%) especially for agriculture, barren, and built-up categories. Since the study area was a rural region, mixing of spectral properties was very common. Barren and built-up were challenging to classify as built-up areas in the study area are situated near the coasts or populated with vegetation such as trees. This confusion is evident in Figure 2, as shown, for example, in Batan where the shorelines are classified as "Built-up". On the other hand, the separation between grassland and agriculture is difficult due to an indigenous agricultural practice (Figure 3). The Ivatans usually practice agriculture in small plots (300 - 500 m^2) and are bordered by hedgerows consisting of reeds or trees (Figure 3a and 3b). Agricultural plots follow a rotation period of farm-to-fallow every 3-5 years that differs for each plot (de Guzman et al., 2014). Therefore, a Landsat image may be acquired in between those periods where it is either an agricultural land or a fallow land. Although Landsat has a constant revisit date (16-day), high cloud cover reduced the chance of imaging the transition. Post-classification cleanup removed instances of Inland Water due to its small size (<8100 m^2).

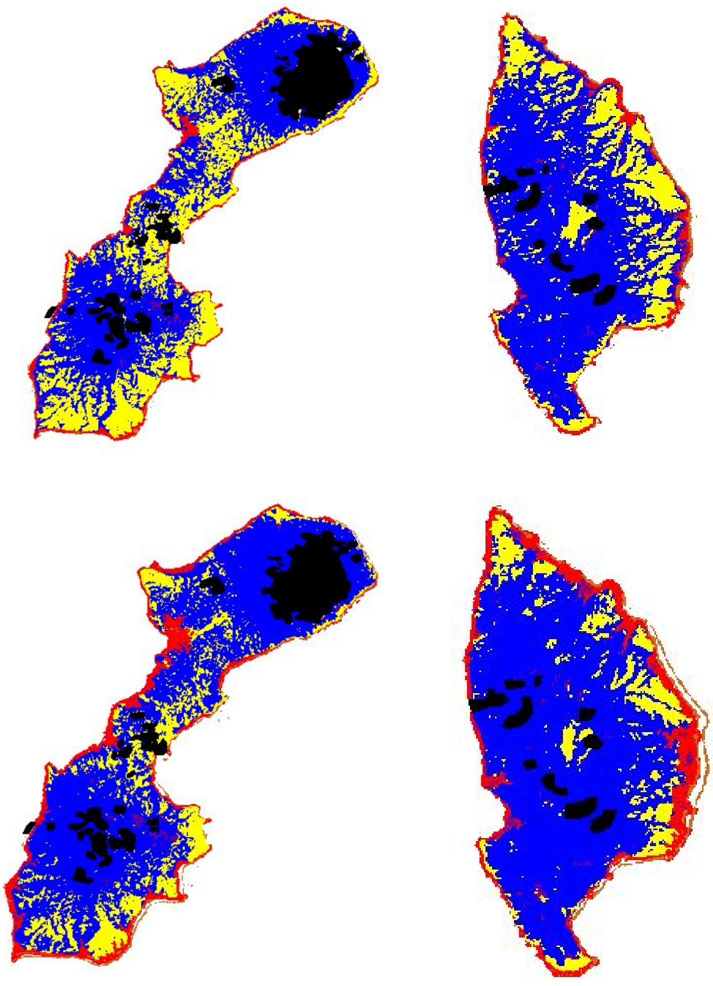

Figure 2. Land cover/Land Use map of the three islands of study, Batan (left), Sabtang (middle), and Itbayat (right) from 1989 (top row) to 2016 (bottom row). Sizes not to scale. Forests are in blue, grasslands in yellow, agriculture in violet, barren in brown, and built-up in red. Clouds are in black. Increase in forest is apparent in Batan and Sabtang.

a b

Figure 3. (a) Field photo taken 2016-01-05 in Tukon (Batan) showing a typical agriculture plot with hedgerows consisting of trees and, (b) high-resolution Google Earth Pro with the approximate location of the photo.

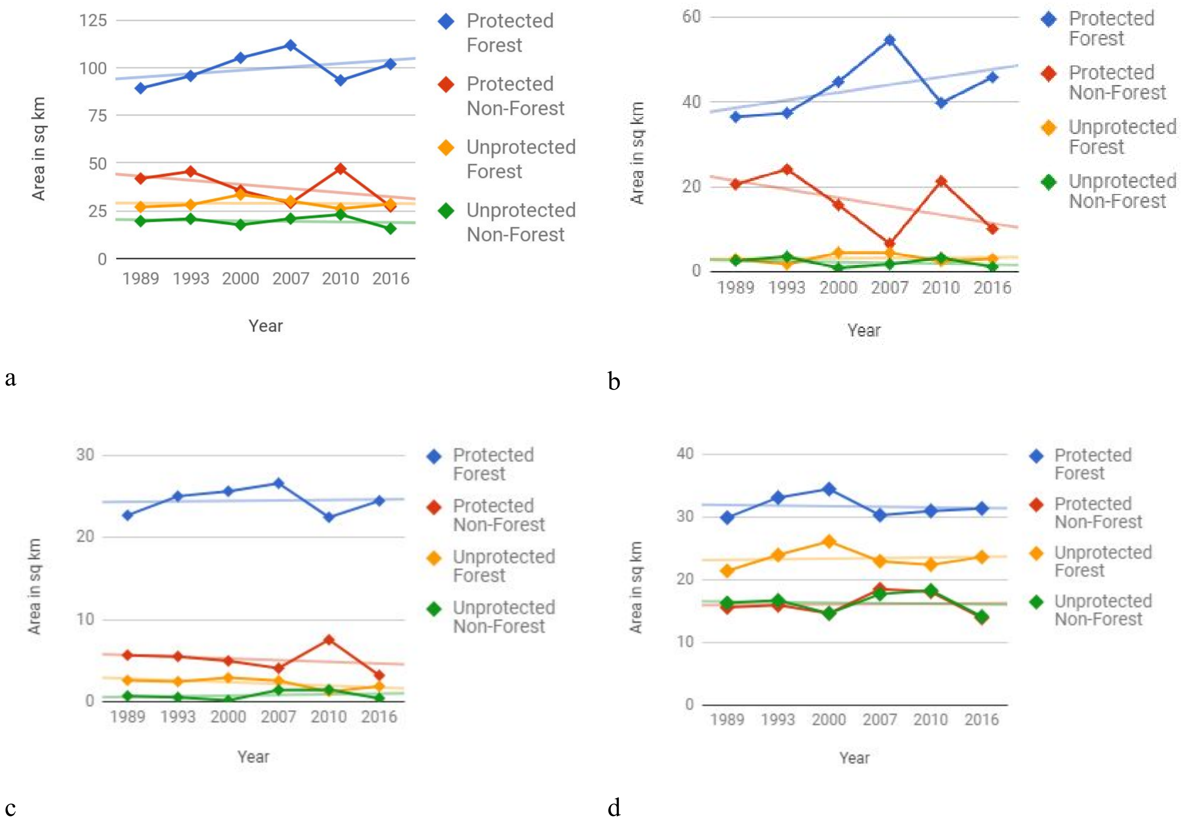

Figure 4. Estimated area of change of Forest and Non-Forest in (a) Batanes, (b) Batan, (c) Sabtang, and (d) Itbayat throughout the study period.

Quantifying the change over the time periods required the merging of grassland and agriculture category into "Non-Forest" (Figure 4). Separate area estimates are calculated from protected and unprotected lands. Results show that there is an increasing trend in forest cover and decreasing trend in non-forest in protection lands. On the other hand, trends in both forest and non-forest in unprotected lands are generally stable. Compared to pre- and post RA 8991, there is an unclear trend whether RA 8991 had an impact on changing LCLUC patterns. However, through a combination of policies extending back to 1988 and cultural practices by the Ivatans, the lands are steadily regaining forest cover. From around a total of 116.16 km^2 of forests in 1989, the province has gained 14.15 km^2 of forest. A dip in estimated forest and non-forest cover can be observed on 2010, however a small regain is observed after six years.

Trends on a per island basis indicate different changes throughout the study period (Figure 4b to 4d). Only Batan (Figure 4b) indicates a trend in increasing forests and decreasing non-forests in protected lands. Sabtang (Figure 4c) indicate a nearly stable trend and also in Itbayat (Figure 4d) although the latter has a larger area that is unprotected and its forest cover in protected lands are decreasing back to 1989 area estimates. Itbayat Island holds a Certificate of Ancestral Domain thus allowing the individuals on the island to practice activities that may contradict the objectives of RA 8991. Particularly, Itbayat can engage in slash and burn farming although the practice is prohibited. A smaller portion of the island is dedicated for protection as its lands are more cultivated.

Figure 5. Sample agricultural plots (encircled in red) in a “Protection Land” in the island of Batan.

The trend of forest and non-forest appear to fluctuate throughout the study period. Inspection of the shapefile separating protected and unprotected lands reveals that many agriculture plots are situated within “Protection Lands” (Figure 5). Lands that are assigned to protection are not properly delineated and are overestimated, therefore including habitats for protected species for protection that is surrounded by agricultural plots.

5. SUMMARY AND CONCLUSION

The study illustrates a method of change detection inside GEE. The platform, developed by Google, is a web-based Earth observation platform that processes satellite data. It produces results using Google’s servers, allowing planetary-wide analysis without relying on a personal computer for processing. The use of GEE revealed strengths and weaknesses, particularly the availability of performing earth observation for researchers at reduced costs and better performance, and the need to further investigate and reprocess the Landsat images then manually upload the data back into GEE, respectively. The normalization method used was satisfactory for the RGB band yet performed outside the benchmark for the NIR band. Although 0.02 RMSE is an arbitrary value (Moran et al., 1992), other normalization procedures must be explored. However, the present capabilities of GEE limit available normalization procedures. Nevertheless, the methodology used in this study is easy to implement and can be replicated to other locations. As processing is passed to Google’s servers, results are obtained faster.

The investigation of Batanes before and after RA 8991 indicate an increasing trend in forest cover. This upward trend implies that the measures established to promote conservation in the province is effective. However, this may not be the cause of RA 8991 alone. RA 8991 is likely one of the other laws enacted in the province that helped decrease threats to the protected area. Additionally, the self-sufficiency of the natives helped decrease further expansion of agricultural lands although the practice of farm-to-fallow induced a significant amount of confusion to classifying true agriculture and grassland areas. Separation of agriculture and grasslands would be better in higher spatial resolution imagery using object-based classification. To avoid overestimation, a better map that separates habitats to those surrounded by anthropogenic disturbance should be utilized.

On a per island analysis, the islands have different trends. Only Batan island has a clear trend of increase. Relatively stable trends are observed in Sabtang and Itbayat. The island of Itbayat can perform activities that may contradict the objectives of RA 8991 due to its Certificate of Ancestral Domain. The activities that the certificate enables essentially conflicts with RA 8991, thus have a critical implication to the future LCLUC trends in the island. The change observed does not explain all of the aspects of LCLUC. Studying the drivers associated with change could reveal underlying and proximate causes that help determine the extent of anthropogenic influence to LCLUC. Overall, the results of this study provide valuable information to protected area managers in the province to assist decision-making and critically analyzing the implications of the observed change to the objectives of RA 8991.

6. REFERENCES

Apan, A., Suarez, L. A., Maraseni, T., & Castillo, J. A. (2017). The rate, extent and spatial predictors of forest loss (2000--2012) in the terrestrial protected areas of the Philippines. *Applied Geography*, *81*, 32–42.

Bastillo, R. (n.d.). Physical and Natural Characteristics. Retrieved April 3, 2017, from http://www.batanes.gov.ph/physical-and-natural-characteristics/

Blolong, F. R. R., & others. (1996). The Ivatan Cultural Adaptation to Typhoons: A Porttrait of a Self-Reliant Community from the Indigenous Development Perspective. *Agham-Tao*, *8*(5).

Briguglio, L. (1995). Small Island Developing States and Their Economic Vulnerabilities. *Pergamon World Development*, *23*(9), 1615–1632. http://doi.org/10.1016/0305-750X(95)00065-K

Bugayong, L. A. (2006). Effectiveness of logging ban policies in protecting the remaining natural forests of the Philippines. In Berlin Conference on Human Dimensions of Global Environmental Change--Resource Policies: Effectiveness, Efficiency, and Equity, held at Freie University, Berlin, Germany, on (pp. 17–18).

Calado, H., Fonseca, C. C., Vergílio, M., Costa, a., Moniz, F., Gil, a., & Dias, J. a. (2014). Small Islands Conservation and Protected Areas. *Revista de Gestão Costeira Integrada*, *14*(2), 167–174. http://doi.org/10.5894/rgci523

Davies, K. P., Murphy, R. J., & Bruce, E. (2016). Detecting historical changes to vegetation in a Cambodian protected area using the Landsat TM and ETM+ sensors. Remote Sensing of Environment, 187, 332–344. http://doi.org/10.1016/j.rse.2016.10.027

de Guzman, L. E. P., Zamora, O. B., Talubo, J. P. P., & Hostallero, C. D. V. (2014). Sustainable agricultural production systems for food security in a changing climate in Batanes, Philippines. *Journal of Developments in Sustainable Agriculture*, *9*(2), 111–119.

DeFries, R., Hansen, A., Turner, B. L., Reid, R., & Liu, J. (2007). Land use change around protected areas: Management to balance human needs and ecological function. *Ecological Applications*. http://doi.org/10.1890/05-1111

DENR-BMB. (2014). *The Fifth National Report to the Convention on Biological Diversity*.

Foody, G. M., & Mathur, A. (2006). The use of small training sets containing mixed pixels for accurate hard image classification: Training on mixed spectral responses for classification by a SVM. Remote Sensing of Environment, 103(2), 179–189. http://doi.org/10.1016/j.rse.2006.04.001

Geldmann, J., Barnes, M., Coad, L., Craigie, I. D., Hockings, M., & Burgess, N. D. (2013). Effectiveness of terrestrial protected areas in reducing habitat loss and population declines. *Biological Conservation*, *161*, 230–238.

La Viña, A. G. M., Kho, J. L., & Caleda, M. J. (2010). Legal framework for protected areas: Philippines. *Gland, Suiza: IUCN*.

Mallari, N. A. D., Collar, N. J., McGowan, P. J. K., & Marsden, S. J. (2016). Philippine protected areas are not meeting the biodiversity coverage and management effectiveness requirements of Aichi Target 11. *Ambio*, *45*(3), 313–322. http://doi.org/10.1007/s13280-015-0740-y

Mangahas, M. F. (1996). Mataw fishing in Batanes.

Mangahas, M. F. (2010). Seasonal ritual and the regulation of fishing in Batanes Province, Philippines. In *Managing Coastal and Inland Waters* (pp. 77–98). Springer.

Moran, M. S., Jackson, R. D., Slater, P. N., & Teillet, P. M. (1992). Evaluation of simplified procedures for retrieval of land surface reflectance factors from satellite sensor output. Remote Sensing of Environment, 41(2–3), 169–184. http://doi.org/10.1016/0034-4257(92)90076-V

Nagendra, H. (2008). Do parks work? Impact of protected areas on land cover clearing. *Ambio*, *37*(5), 330–7. http://doi.org/10.1579/06-R-184.1

Nagendra, H., Lucas, R., Honrado, J. P., Jongman, R. H. G., Tarantino, C., Adamo, M., & Mairota, P. (2013). Remote sensing for conservation monitoring: Assessing protected areas, habitat extent, habitat condition, species diversity, and threats. Ecological Indicators, 33, 45–59. http://doi.org/10.1016/j.ecolind.2012.09.014

Paulay, G. (1994). Biodiversity on oceanic islands: Its origin and extinction. *Integrative and Comparative Biology*, *34*(1), 134–144. http://doi.org/10.1093/icb/34.1.134

Pelling, M., & Uitto, J. I. (2001). Small island developing states: natural disaster vulnerability and global change. *Global Environmental Change Part B: Environmental Hazards*, *3*(2), 49–62. http://doi.org/http://dx.doi.org/10.1016/S1464-2867(01)00018-3

PSA. (2016). Highlights of the Philippine Population 2015 Census of Population. Philippine Statistics Authority. Retrieved from https://www.psa.gov.ph/content/highlights-philippine-population-2015-census-population

Song, C., Woodcock, C., Seto, K. ., Lenney, M. ., & Macomber, S. . (2001). Classification and change detection using Landsat TM Data- When and how to correct atmospheric effects? Remote Sensing of Environment, 75(0), 230–244. http://doi.org/10.1016/S0034-4257(00)00169-3

Townshend, J. R. G., Gurney, C., McManus, J., & Justice, C. O. (1992). The Impact of Misregistration on Change Detection. *IEEE Transactions on Geoscience and Remote Sensing*, *30*(5), 1054–1060. http://doi.org/10.1109/36.175340
Townshend, J. R. G., Gurney, C., McManus, J., & Justice, C. O. (1992). The Impact of Misregistration on Change Detection. *IEEE Transactions on Geoscience and Remote Sensing*, *30*(5), 1054–1060. http://doi.org/10.1109/36.175340
USGS. (2011). Landsat 7 Science Data Users Handbook. National Aeronautics and Space Administration, 1–186.

Vermote, E., Justice, C., Claverie, M., & Franch, B. (2016). Preliminary analysis of the performance of the Landsat 8/OLI land surface reflectance product. Remote Sensing of Environment, 185, 46–56. http://doi.org/10.1016/j.rse.2016.04.008

Yang, X., & Lo, C. P. (2000). Relative radiometric normalization performance for change detection from multi-date satellite images. Photogrammetric Engineering and Remote Sensing, 66(August), 967–980.