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SPATIO-TEMPORAL MAPPING, BIOMASS AND CARBON STOCK ASSESSMENT OF MANGROVE FOREST IN ABORLAN, PALAWAN, PHILIPPINES

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ABSTRACT – Mangrove forests are one of the productive biological systems that play significant functions in the context of ecosystem services and climate change mitigation through carbon capture and storage. In this study, mangrove cover change, biomass, and carbon stock were assessed in Aborlan, Palawan. Spatial and temporal mangrove distribution map for 1992-2014 were generated at 30-m resolution using Landsat satellite images. Six nested-plots with a size of 20 m x 100 m were established to determine species diversity, biomass and carbon stock. Results show that the mangrove forest in the area had increased by 372.06 hectares for the period of 22 years, attributed to community mangrove protection program. The Shannon-Wiener diversity index (H' = 1.8993) was very low having a total of ten true mangrove species identified dominated by Rhizophora mucronata Lam. Among the mangrove stands, 74.46 % of the total biomass was credited to the above-ground (213.72 t ha-1) while 25.54 % was attributed to the belowground (73.72 t ha-1). The total carbon stored were 129.39 t C ha-1. These values reflect the fact that mangrove forest store a substantial amount of carbon, an essential information towards the formulation of evidence-based conservation programs.

Key words: Palawan mangrove, allometric equations, biomass, carbon content, change detection, Landsat

INTRODUCTION

Mangrove forests comprised of halophytic plant species that form the critical boundary between terrestrial, estuarine, and near-shore marine ecosystems in tropical and subtropical regions (Osborne, 2012 and Kathiresan and Bingham, 2001). They are among the world's most productive ecosystem producing vast organic carbon that nourishes and support coastal ecosystem and contributing significantly to the global carbon cycle (Donato et al., 2011). Barbier et al (2011) found out that mangrove ecosystem services, processes, and functions had economic value ranges from 14,166-16,142 US$/ha-^{1} for the services like raw materials and food, maintenance of fisheries, erosion control, coastal protection, and carbon sequestration. A greater attention is focused on the tropical forest to offset the carbon emissions due to its cost effective, high potential carbon uptake, and associated environmental and social benefits (Leni at al.,2011; and Polidoro et al., 2010). Mangrove forest not only sequesters the vast amount of carbon dioxide but they also have protective roles in mitigating impacts of climate changes such as providing tidal belts against storm surges and abrupt rise in the sea level.

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Despite important ecological, socio-economic and recreation importance of mangrove in the Philippines, still, it is under threats due to different anthropogenic activities. It has been reported that Philippines had 256,185 hectares of mangroves circa 2000 (Long et al., 2013). A fairly extensive mangrove forest in the country can only be found in Palawan. Owing to its vast mangrove cover, Presidential Proclamation No. 2152 of 1981 declared the entire province of Palawan as Mangrove Swamp Forest Reserve. At local level, there is a dearth of research effort dealing with mangrove carbon stock assessment, and spatio-temporal assessment using remote sensing techniques. Thus, this study evaluated the mangrove cover change from 1992-2014 using remote sensing, determined the above-ground and below ground biomass, and calculated carbon stock stored mangrove forest of Aborlan, Palawan. This study also identified the influences that affect the increase/decrease of mangrove cover in the area.

Materials and Methods

Study site

This study was carried out in a mangrove stand in the coastal community of Sitio Marikit ($9^0$26’44.97” N $118^0$35’16.62”) and Malunao Island ($9^0$26’37.64” N $118^0$37’11.72”), San Juan, Aborlan, Palawan, Philippines. Palawan is an elongated island, with 1,768 small islands and islets. It has a total of 1,789.655 ha that is administratively divided into 23 municipalities and highly-urbanized city, the City of Puerto Princesa. The entire island of Palawan was a designated Man and Biosphere Reserve, an Endemic Bird Area, with two internationally-recognized World Heritage Sites, and a Philippine Priority Area for biodiversity conservation (Anda and Tabangay-Baldera, 2009). The biological diversity of the Palawan Corridor is rich and spectacular. Its marine ecosystem boasts of an astonishing assemblage of marine life and is one of the richest and most biologically important in the world (Diesmos and Palomar, 2004). With vast areas of pristine mangrove areas, the whole province of Palawan was declared as Mangrove Forest Reserves by virtue of Presidential Proclamation No. 2152, series of 1981. Long et al.(2013) mapped and monitored Philippine mangroves through remote sensing and they found out the Palawan mangroves has a total of 56,261 hectares or approximately 22.23 percent of Philippines total mangrove area.

The municipality of Aborlan is a first class municipality, located in the central part of Palawan island (Figure 1). It is located 69 kilometers from the highly urbanized city of Puerto Princesa. It has a total of 807.33 square kilometers divided into 19 barangays.

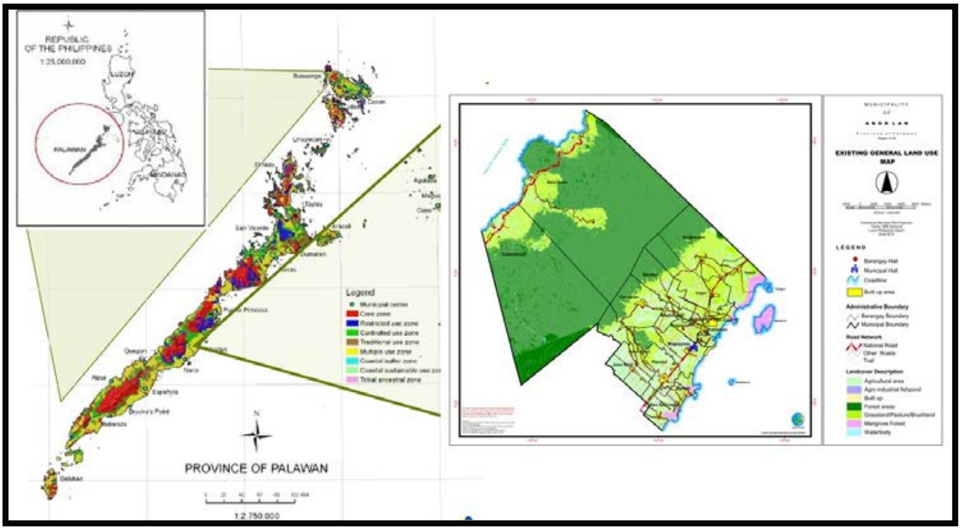

Figure 1.Location map of the study area.

Mangrove Cover Change Data Collection

In order to estimate the mangrove cover over the last 22 years (1992-2014), a Landsat 5 (March 1992) and Landsat 8 (March 2014) images were downloaded from www.earthexplorer.usgs.gov. Downloaded images were subjected to radiometric calibration and Fast Line-of-Sight Atmospheric Analysis of Spectral Hypercubes (FLAASH) atmospheric correction using Envi 5.1 software. Calibrated images were classified using Maximum Likelihood algorithm. Training data were categorized into three class: mangrove; terrestrial non-mangrove and water. Final classified maps were overlaid to generate a mangrove cover change map of the study sites.

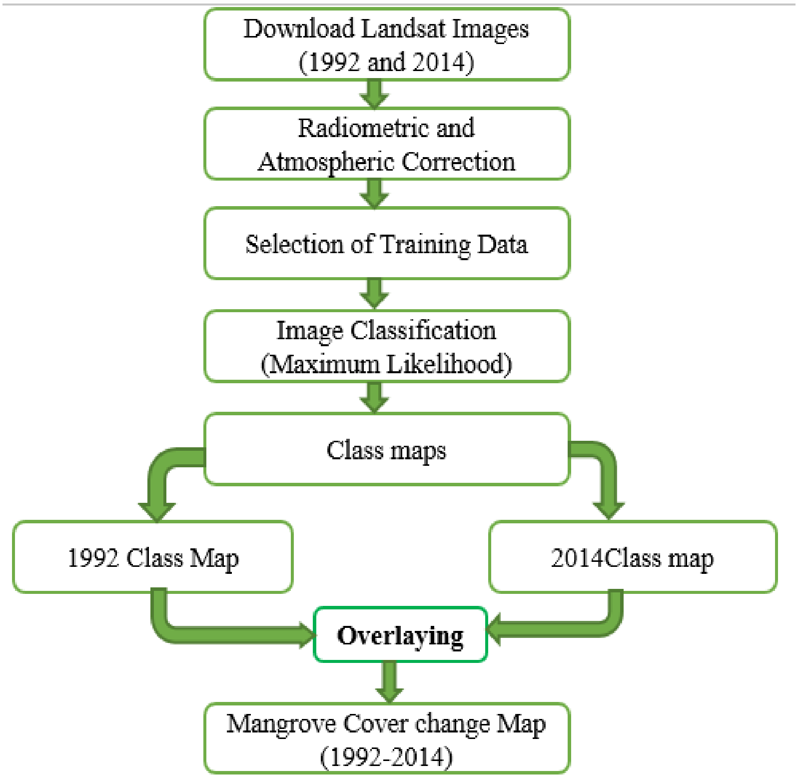

Figure 2. Change detection flow using satellite images.

Species composition, biomass, and Carbon stock

Following the method by Hairiah et al (2004),a non-destructive method of biomass estimation was used in this study. Six sample plots were established using nested plot, in every plot four small plots (5 m x 40 m) for trees with 5-30 cm dbh (diameter at breast height) and large plot (20 m x 100 m) to record tree with a diameter of more than 30 cm. within sample plot. All trees with at least 5 cm diameter were identified together with their diameter and height (Figure 3). Trees species were identified using mangrove handbook by Primavera et al. (2004). Sample plots were selected based on their mangrove canopy cover, and the criteria used by Deguit et at. (2004).

Figure 3. Measurement of tree diameter. Photo credit: Reagan Venturillo.

Mangrove community's species diversity was computed using Shannon-Wiener index. The species diversity has been calculated as follow:

where *H'* is the diversity index, p_i is the proportion of individuals of species *i* and ln is natural logarithm.

For the determination of above-ground biomass (W_{agb}) and below-ground biomass (W_R), allometric equations for Southeast East Asian mangroves developed by Komiyama et al. (2005) were used in this study. The estimation equations of W_{agb} and W_R have a coefficient of determination (R^2) of 0.98 and 0.95, respectively. The following allometric were used in the calculations of W_{agb} and W_R.

where *p* is the wood density of the species, and *D* is the diameter.

All tree biomass (both W_{agb} and W_R) for each plot was summed to get the total biomass expressed in tons. Biomass was converted to the equivalent amount of C by multiplying the biomass by 0.46, an average carbon content value for mangrove species based on Kauffman et al. (2011). Carbon stock was determined as the product of the carbon concentration and the corresponding biomass of the individual tree.

Factors that may have affected the increase and decrease of mangrove cover in the area was noted, together with different natural and anthropogenic activities that have negative impacts to the mangrove area.

RESULTS AND DISCUSSION

Mangrove Cover Change

Based on the results of change detection test there is a substantial increase of mangrove forest cover in the area. During 1992, around 1,494.80 has of mangrove forest were detected and it goes to 1 866.87 has in 2014, thus increasing the mangrove cover of 372.06 has for the period of 22 years (Figure 4a, 4b, 4c,and 5).

a b c

Figure 4. Mangrove cover map of 1992 (a), 2014 (b), and change map (C), wherein the red area represents an increase in cover.

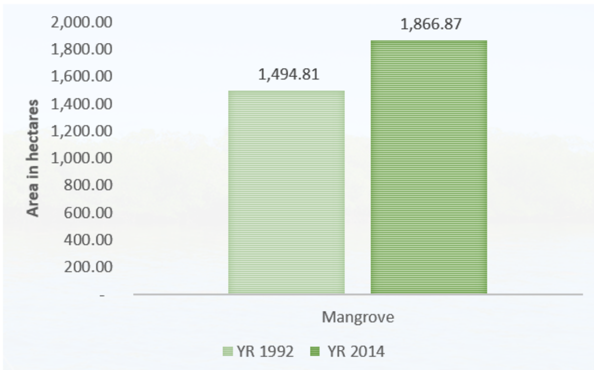

Figure 5. Mangrove area in hectares.

The increase in mangrove cover in the area is the result of the partnership between government, non-government organizations, local government units, and local community. The environment in Palawan is governed by a special national law known as Strategic Environmental Plan for Palawan under RA 6711. Under SEP Law, a framework is known as Environmental Critical Area Network serves as a basis for its management. Under ECAN, all mangrove areas in the province are under marine core zone, means no destructive forms of activities is allowed. The local community also has a significant contribution to the protection of mangrove area. For example, a coastal community in Tagpait Aborlan known as Tagpait Coastal Development Association (TACDA) was organized in 1992 by Japan-based OISCA (Organization for Industrial, Spiritual, and Cultural Advancement International). One of their major projects is mangrove afforestation project, wherein member-families are obliged to plant one hectare of mangrove in their coastal area.

Species composition, biomass and carbon stock

The species composition of mangrove stand in the eastern portion of Aborlan, Palawan, together with their corresponding number of individuals and Shannon-Wiener diversity index is shown in Table 1. Among the families, *Rhizophoraceae* has the most number of species (6), followed by *Meliaceae* (2) while *Myrsinaceae* and *Sonneratiaceae* had one species each. A total of ten true mangrove species were measured, of which *Rhizophora mucronat*a, *Rhizophora apiculata* and *Xylocarpus granatum* were observed in all of the plots. With regards to species diversity index, the calculated Shannon-Wiener index was H'= 1.8993. This diversity index was considered very low based on the scale used by Gevaña and Pampolina (2009). This reflects the dominance of few species particularly *R. mucronata* and *R. apiculata* over other species in terms of frequency. Diversity index in this area was higher compared to Tinuiguiban Cove, Puerto Princesa City with 0.851 (Becira, 2006). Among the mangrove species in the area, only the *Ceriops decandra* was identified by IUCN as near-threatened due to its decreasing population caused by localized threats.

Table 1. Mangrove species in the area, together with their number of individuals, and Shannon-Wiener diversity index.

Family	Species	No. of individual	*H'*
Myrsinaceae	*Aegiceras floridum*	11	0.0943
Meliaceae	*Xylocarpus granatum*	37	0.2119
	Xylocarpus moluccensis	6	0.0599
Rhizophoraceae	*Bruguiera gymnorrhiza*	41	0.2250
	Bruguiera parviflora	10	0.0879
	Ceriops decandra	11	0.0943
	Ceriops tagal	28	0.1786
	Rhizophora apiculata	97	0.3367
	Rhizophora mucronata	138	0.3650
Sonneratiaceae	*Sonneratia alba*	48	0.2457
Total		427	1.8993

Biomass of a forest stand can be computed using allometric computation; in fact, this method is also non-destructives. Komiyama et al. (2005) in their study, they used stem diameter and wood density. These two variables influenced the biomass and carbon stocks of individual tree species. Based on the results of computation, the total biomass was estimated to be from 22 t ha^{-1} to 542.29 t ha^{-1}, with a mean of 287.54 542.29 t ha^{-1}. Using an average carbon content value for tropical trees of 0.46 (Kauffman et al., 2011), the C-stock of the biomass ranged from 10.15 t C /ha^{-1} to 244 t C /ha^{-1} with a mean of 129.39 t C /ha^{-1} are stored in the biomass of mangrove both above-ground and below-ground. As observed, large trees like *X. granatum* have large girths , hence have higher carbon stocks. The result of the biomass estimates obtained in this study is within the global range of 7.9 t ha^{-1} (Lugo and Snedaker, 1974) to 460 t ha^{-1} (Putz and Chan, 1986). However, it is lower compared to the estimated mean biomass of mangroves in the Philippines which is 409 t ha^{-1} with an equivalent stored carbon of 184 t C /ha^{-1} (Lasco and Pulhin, 2004). According to Alongi (2012) in the review of carbon sequestration in mangrove forest, the variation the carbon sequestration within a mangrove tree is affected by species composition, salinity, light intensity, nutrient availability, tidal action, temperature, and climate.

In this study, it was found out that above-ground biomass corresponds to 74.42%,while the remaining 25.56% was attributed to the below-ground. In terms of above-ground biomass to below-ground biomass (*T/R*) ratio, values ranged from 2.29 to 3.07, with a mean of 2.76. The *T/R* value in this study is within the *T/R* ratio of mangrove forests varied between 1.1 to 4.4 (Komiyama, 2008). Thus, not only the aboveground biomass of mangroves consists of stem, branch and leaf contains a substantial amount of carbon, large amount of carbon is allocated to the root system.

At present, very few studies are available on the estimation of carbon stock in a natural forest in the Philippines. As presented in Table 2, it was found out the generated value of carbon stock is relatively higher than that of San Juan, Batangas (Gevana & Pampolina, 2009), but lower compared to Bahile, Puerto Princesa (Abino et al., 2014), Pagbilao, Quezon (Almazon et al.; and Lasco et al. ,2000), and Pinacdao, Samar (Abino, et al, 2014). The variations in results could be because of: species, ecological conditions, geographical locations, sample size, wood density variability and the type of forest i.e natural or planted (Alemayehu et al, 2014 and Komiyama et al, 2005).

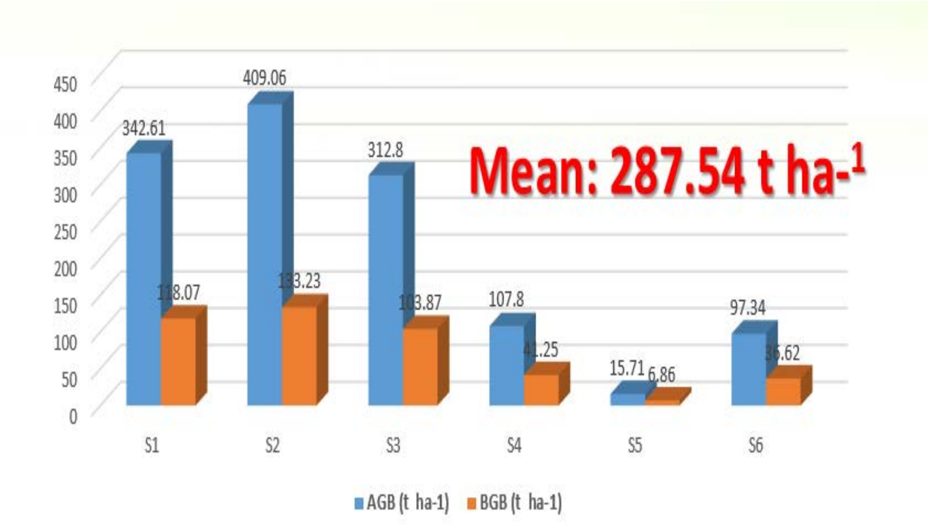

Figure 5. Biomass of mangrove in the area.

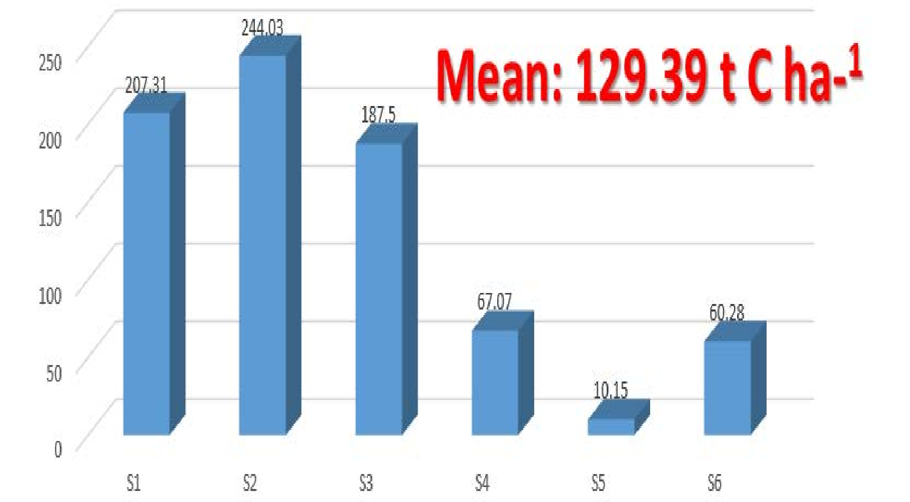

Figure 6. Carbon stock of mangrove in the area.

Table 2 .Comparison of different carbon stock assessment conducted in the Philippines.

Location	**Condition**	**Carbon stock (t C ha-^{1})**	**Reference**
Pagbilao, Quezon	Natural	178.80	Lasco et al. ,2000
San Juan, Batangas	Natural (private)	115.45	Gevana & Pampolina, 2009
Pinabacdao, Samar	Natural	188.50	Abino, et al, 2014
Bahile, Puerto Princesa City	Natural	263.80	Abino, et al, 2014
Aborlan, Palawan	Natural	129.39	This study

Threats to Mangrove Area

Human-induced activities that may have negative impacts to the mangrove community were recorded. At present, the mangrove forest of Malunao Island is facing some threats, like cutting of trees for housing and fish pens. In Sitio Marikit, the construction of port gives way to the destruction of some patches of mangroves in the area. There is also an evidence of mangrove cutting by nearby residents for their housing and fences. Since there is a community beside the mangrove area, improper solid waste disposal is a really a problem in the area (Figure 7). Alongi (2012) pointed out that the major threats to mangrove areas have been urban development, aquaculture, mining, exploitation of timber for domestic use. PCSDS (2015) also reported that some mangrove areas in Palawan have inadequate to logged-over mangrove density, furthermore the continuous human pressure on mangrove forest like fishpond development, cutting for domestic and economic purposes, conversion to settlement areas and other uses. Thus, there is an urgent need to formulate a conservation program for the management of mangrove resources.

(b)

(a)

(c)

(d)

Figure 7. Mangrove under threats: (a) Residential settlements are encroaching the mangrove forest through time; (b) the local community cleared a portion of mangrove serves as a docking area for their bancas; (c) improper waste problem;(d) and the threat of sea-level rise. Photo credit: Reagan Venturillo.

CONCLUSION AND RECOMMENDATIONS

A total of ten true mangrove species were found in the area, dominated by *Rhizophora mucronata* Lam. Mangroves have shown an increase in areas during the past 22 years(1994-2014). Community afforestation projects, together with strict mangrove policies facilitated the increase of mangrove cover. This mangrove area store a substantial amount of carbon, with a mean Carbon storage of 129.39 t C ha-^{1}. However, it is under threats due to destructive anthropogenic activities documented in the area such as wood cutting for domestic uses and improper solid waste disposal. This information may assist the decision-makers, and development workers in using evidence-based decision-making process for the rehabilitation, conservation, and management of remaining mangroves area, and to restore degraded mangrove forest. Continuous monitoring and assessment of mangrove in this area are recommended due to its several important ecosystem services and functions. Ecotourism activities can also be developed in the area like bird watching activities, island hopping, and mangrove paddle boat tour.

STATEMENT OF AUTHORSHIP:

This study was part of the special problem of the author for the Master of Science in Environmental Science at the University of the Philippines Diliman Campus. Data collection and analysis and final paper was done primarily by the author.

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REFERENCES

Abino, A.C., Castillo, J.A., & Lee Y.L. (2014). Assessment of species diversity, biomass and carbon sequestration potential of a natural mangrove stand in Samar, the Philippines. *Forest Science and Technology*, 10:1, 2-8, DOI: 10.1080/21580103.2013.814593.

Abino, A.C., Castillo, J.A., & Lee Y.L. (2014). Species diversity, biomass, and carbon stock assessments of a natural mangrove forest in Palawan, Philippines. *Pak. J. Bot.*, 46(6): 1955-1962, 2014.

Alemayehu, F., Richard, O., Mwangi K. and Wasonga, O. 2014. Assessment of Mangrove Covers Change and Biomass in Mida Creek, Kenya. *Open Journal of Forestry,* 2014, 4, 398-413.

Almazol, A.E., Cervancia, C.R., Buot, I. JR. E., Gruezo, W.Sm., Pampolina, N.M. 2013**.** *IAMURE International Journal of Ecology and Conservation 7* (Jul 2013): 25-39.

Anda, R.D. & Tabangay-Baldera, J.G. (eds). (2004). Surublien: Strategies to Conserve Palawan's Biodiversity . Provincial Government of Palawan, Palawan Council for Sustainable Development Staff, Department of Environment and Natural Resources-MIMAROPA Region IV, Palawan NGO Network, Inc., and Conservation International Philippines, Puerto Princesa City, Philippines. 124pp.

Barbier, E.B., Hacker, S.D., Kennedy,C., Koch, E.W., Tier, A.C., and B.R. Silliman. 2011. The value of estuarine and coastal ecosystem services*. Ecological Monographs*, 81(2), 2011, pp. 169–193.

Becira, E.M. 2005. State of Mangroves in Tiniguiban Cove, Puerto Princesa Bay, Puerto Princesa City, Palawan. *Science Diliman* (July-December 2005) 17:2, 46-51.

Deguit, E. T., Smith, R. P., Jatulan W. P., & White A.T. **(**2004). Participatory Coastal Resource Assessment Training Guide, Coastal Resource Management Project of the Department of Environment and Natural Resources, Cebu City, Philippines.134 pp.

Diesmos, A. and Palomar, N. 2004. The status of biological diversity in the Palawan Corridor. In: Anda, R.D. and Tabangay-Baldera, J.G. (Eds.). Surublien: Strategies to Conserve Palawan's Biodiversity. Puerto Princesa City: Provincial Government of Palawan, Palawan Council for Sustainable Development Staff, Department of Environment and Natural Resources, Palawan NGO Network, Inc., and Conservation International Philippines, pp. 1–7.

Donato DC, Kauffman JB, Murdiyarso D, Kurnianto S, Stidham M, et al. (2011). Mangroves among the most carbon-rich forests in the tropics. *Nature Geoscience* 4: 293–297. doi:10.1038/ngeo1123.

Duke, N., Kathiresan, K., Salmo III, S.G., Fernando, E.S., Peras, J.R., Sukardjo, S. & Miyagi, T. 2010. *Ceriops decandra*. The IUCN Red List of Threatened Species 2010: e.T178853A7627935. http://dx.doi.org/10.2305/IUCN.UK.2010-2.RLTS.T178853A7627935.en. Downloaded on 29 August 2016.

Gevaña, D T and Pampolina, N M. (2009). Plant diversity and carbon storage of a *Rhizophora* stand in Verde Passage, San Juan, Batangas, Philippines. *J. Environ. Sci. Manag*, 12(2): 1–10.

Hairiah, K., Sitompul, S.M., Van Noorwijk, M. & Palm C. (2001). Methods for Sampling Carbon Stocks Above and Below Ground. International Center for Research in Agroforestry, ASB Lecture Series Note 4B, Bogor, Indonesia, 23 pp.

Kathiresan, K. & B.L. Bingham. (2001). Biology of mangroves and mangrove ecosystems. *Advances in Marine Biology* vol. 40: 81-251.

Kauffman, J.B., Heider, C., Cole, T.G., Dwire, K.A. & Donato, D.C. (2011). Ecosystem carbon stocks of Micronesian mangrove forests. *Wetlands,* 31, 343–352.

Komiyama A, Poungparn S, & Kato S. (2005). Common allometric equations for estimating the tree weight of mangroves. *J Trop Ecol*. 21:471–477.

Komiyama, A., Ong, J.E. and Poungparn S. 2008. Allometry, biomass, and productivity of mangrove forests: A review. *Aquatic Botany 89* (2008) 128–137 doi:10.1016/j.aquabot.2007.12.006.

Lasco, R.D. and F.B.Pulhin. 2004. Carbon budgets of tropical forest ecosystems in Southeast Asia: implications for climate change. In: Forestry for poverty reduction: opportunities with clean development mechanism, environmental services and biodiversity, (Eds.): Sim, H.C., S. Appanah and Y.C. Youn. RAP Publication, 22: 61-75.

Leni D., Camacho, L.D., Dixon T., Gevaña, D.T., Carandang, A.P., Camacho, S.C., Combalicer, E.A., Rebugio, L.L. & Yeo-Chang Youn (2011). Tree biomass and carbon stock of a community-managed mangrove forest in Bohol, Philippines, *Forest Science and Technology*, 7:4, 161-167, DOI: 10.1080/21580103.2011.621377

Long, J.; Napton, D.; Giri, C., and Graesser, J., (2014). A mapping and monitoring assessment of the Philippines' mangrove forests from 1990 to 2010. *Journal of Coastal Research*, 30(2), 260–271. Coconut Creek (Florida), ISSN 0749- 0208. http://dx.doi.org/10.2112/JCOASTRES-D-13-00057.1

Lugo, A.E., Snedaker, S.C., 1974. The ecology of mangroves. Ann. Rev. Ecol. Syst. 5, 39–64.

Osborne, P.L. (2012). *Tropical Ecosystem and Ecological Concepts*. Second Edition. Cambridge University Press.

PCSDS (2015): State of the Environment 2015 Updates, Province of Palawan,Philippines. Palawan Council for Sustainable Development, Puerto Princesa City.

Polidoro, B.A., K.E. Carpenter, L. Collins, N.C. Duke, A.M. Ellison, J.C. Ellison, E.J. Farnsworth, E.S. Fernando, K. Kathiresan, N.E. Koedam, S.R. Livingstone, T. Miyagi, G.E. Moore, V.N. Nam, J.E. Ong, J.H. Primavera, S.G. Salmo III, J.C. Sanciangco, S. Sukardjo, Y. Wang, and J.W.H. Yong. (2010). The Loss of Species: Mangrove Extinction Risk and Geographic Areas of Global Concern. *PLoS ONE* 5(4): e10095. doi:10.1371/journal.pone.0010095

Primavera, J.H., R.B. Sadaba, M.J.H.L. Lebata, and J.P. Altamirano. (2004). Handbook of Mangroves in the Philippines – Panay. SEAFDEC Aquaculture Department (Philippines) and UNESCO Man and the Biosphere ASPACO Project, 106 pp.

Putz, F., Chan, H.T., 1986. Tree growth, dynamics, and productivity in a mature mangrove forest in Malaysia. *Forest Ecol. Manage*. 17, 211–230.

Samson, M.S. and R.N. Rollon 2008. Growth Performance of Planted Mangroves in the Philippines: Revisiting Forest Management Strategies. *Ambio* Vol. 37, No. 4, June 2008

Lasco, R.D. and F.B.Pulhin. 2004. Carbon budgets of tropical forest ecosystems in Southeast Asia: implications for climate change. In: Forestry for poverty reduction: opportunities with clean development mechanism, environmental services and biodiversity, (Eds.): Sim, H.C., S. Appanah and Y.C. Youn. RAP Publication, 22: 61-75.

Leni D., Camacho, L.D., Dixon T., Gevaña, D.T., Carandang, A.P., Camacho, S.C., Combalicer, E.A., Rebugio, L.L. & Yeo-Chang Youn (2011). Tree biomass and carbon stock of a community-managed mangrove forest in Bohol, Philippines, *Forest Science and Technology*, 7:4, 161-167, DOI: 10.1080/21580103.2011.621377

Long, J.; Napton, D.; Giri, C., and Graesser, J., (2014). A mapping and monitoring assessment of the Philippines' mangrove forests from 1990 to 2010. *Journal of Coastal Research*, 30(2), 260–271. Coconut Creek (Florida), ISSN 0749- 0208. http://dx.doi.org/10.2112/JCOASTRES-D-13-00057.1

Lugo, A.E., Snedaker, S.C., 1974. The ecology of mangroves. Ann. Rev. Ecol. Syst. 5, 39–64.

Osborne, P.L. (2012). *Tropical Ecosystem and Ecological Concepts*. Second Edition. Cambridge University Press.

PCSDS (2015): State of the Environment 2015 Updates, Province of Palawan,Philippines. Palawan Council for Sustainable Development, Puerto Princesa City.

Polidoro, B.A., K.E. Carpenter, L. Collins, N.C. Duke, A.M. Ellison, J.C. Ellison, E.J. Farnsworth, E.S. Fernando, K. Kathiresan, N.E. Koedam, S.R. Livingstone, T. Miyagi, G.E. Moore, V.N. Nam, J.E. Ong, J.H. Primavera, S.G. Salmo III, J.C. Sanciangco, S. Sukardjo, Y. Wang, and J.W.H. Yong. (2010). The Loss of Species: Mangrove Extinction Risk and Geographic Areas of Global Concern. *PLoS ONE* 5(4): e10095. doi:10.1371/journal.pone.0010095

Primavera, J.H., R.B. Sadaba, M.J.H.L. Lebata, and J.P. Altamirano. (2004). Handbook of Mangroves in the Philippines – Panay. SEAFDEC Aquaculture Department (Philippines) and UNESCO Man and the Biosphere ASPACO Project, 106 pp.

Putz, F., Chan, H.T., 1986. Tree growth, dynamics, and productivity in a mature mangrove forest in Malaysia. *Forest Ecol. Manage*. 17, 211–230.

Samson, M.S. and R.N. Rollon 2008. Growth Performance of Planted Mangroves in the Philippines: Revisiting Forest Management Strategies. *Ambio* Vol. 37, No. 4, June 2008

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