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Vegetation resistance and regeneration potential of *Rhizophora, Sonneratia,* and *Avicennia* in the Typhoon Haiyan-affected mangroves in the Philippines: Implications on rehabilitation practices

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Abstract

Typhoons cause damage to mangrove ecosystems, hampering the delivery of ecosystem goods and services, including coastal protection. We examined the vegetation resistance (VR) and seedling regeneration potential (SRP) of three mangrove genera: *Rhizophora, Sonneratia,* and *Avicennia* at the seafront areas. We assessed genus-specific resistance to and recovery from the impacts of Typhoon Haiyan, by far the strongest storm to make landfall in recorded history. VR was estimated using density, tree height, and diameter at breast height (DBH). SRP was measured as the post-disturbance seedling growth rate within a given plot. Thirty-six 3-m radius plots were established in the typhoon-affected mangrove areas of Ormoc City and Tacloban City in Leyte; and Quinapondan and General MacArthur in Eastern Samar. Results showed that *Avicennia* and *Sonneratia* species yielded the higher average VR values compared to *Rhizophora*, which had the lowest VR across all sites. The different genera could also be arranged from highest to lowest SRP: *Avicennia* (67.27 ± 2.62 cm yr^{-1}) > *Rhizophora* (32.46 ± 4.64 cm yr^{-1}). Overall, our findings on the higher relative VR and SRP values of *Sonneratia* and *Avicennia* call for a shift to these species in mangrove planting at the seafront areas, which currently favor *Rhizophora.*

Keywords: Typhoon Haiyan · seedling recruitment · vegetation resistance · mangrove restoration

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Introduction

Mangrove ecosystems provide numerous ecosystem goods and services to local communities (Polidoro et al., 2010). Coastal protection ranks as the most valuable ecological services that mangrove ecosystems provide (Barbier et al., 2010). During typhoons, storm surges, and tsunamis, mangroves serve as the “first line of defense” by absorbing the wave energy brought about by these disturbances (McIvor, Spencer, Moller, & Splading, 2012; Tanaka, 2009). Mangrove cover stretching at least one kilometer from the costline can attenuate wave height by at most 50 cm (Zhang et al., 2012).

However, worldwide mangrove cover continues to decline, and most prominently in Southeast Asia (Polidoro et al., 2010). Mangrove cover in the Philippines, for example, has devolved from huge contiguous blocks into small, scattered patches. Therefore, there is a need to evaluate the protective function and the capacity to recover of existing mangroves in such conditions.

Typhoon Haiyan (local name: Yolanda) hit the Philippines on November 8, 2013, passing through the islands of Samar, Leyte, Cebu, Panay, and Coron. Haiyan was considered the strongest recorded storm in recent years, bearing wind speeds of 315 kph (Lagmay et al., 2014). Consequently, it generated storm surges as high as 5-6 meters (Mori et al., 2014) in Tacloban City. The typhoon disturbed mangrove ecosystems at varying degrees, causing leaf defoliation, stem breakage, uprooting and mortality (Salmo III, Lovelock, & Duke, 2014; Sherman, Fahey, & Martinez, 2001).

The study evaluated the resiliency of mangrove stands dominated by three mangrove genera: *Rhizophora, Sonneratia,* and *Avicennia*. The study also identified wave resistant and quick-recovering mangrove species. The identification of these resilient mangrove species guide priorities for mangrove rehabilitation and protection.

Materials and Methods

Study Sites

The study sites are the Typhoon Haiyan-disturbed mangrove forests of Tacloban City and Ormoc City in Leyte; and Quinapondan and General MacArthur in Eastern Samar, where storm surges and strong winds were the primary cause of mangrove damage. The degree of damage varied across all sites and may be attributed to their geographical location and forest cover. The survey was done during the period of May-June 2014, approximately six to seven months after Typhoon Haiyan.

The mangroves in Tacloban City come in small patches and are often situated within an immediate community. In Barangay 83-A, Tacloban City, the mangrove cover is dominated by 25-year old planted *Rhizophora apiculata* stands, and natural growth of *Avicennia marina*. Further inland are *Nypa fruticans* that are being harvested by the communities for shingles.

The mangrove forest in Ormoc City is situated in the western portion of Leyte province. The site covers a vast expanse of mangrove cover but it is being encroached on by fishpond operators. Along the seafront are natural stands of *Rhizophora, Sonneratia,* and *Avicennia* species while further inland are covered with nipa and coconut plantations. The said area is co-managed actively by the local government and the local community.

The mangrove study site in Quinapondan and General MacArthur is part of an intact and continuous coastal greenbelt along the coast of Matarinao Bay. Along the seafront are predominantly *Rhizophora, Sonneratia,* and *Avicennia* species, with occurrences of *Bruguiera* and *Aegiceras* species. Further inland are the genus *Lumnitzera, Bruguiera, Xylocarpus*, and *Camptostemon* species, making the said site the most diverse among other study sites. Plots within this study site had sightings of mature trees characterized by large stem diameter, and propagules and fruits larger than their average sizes.

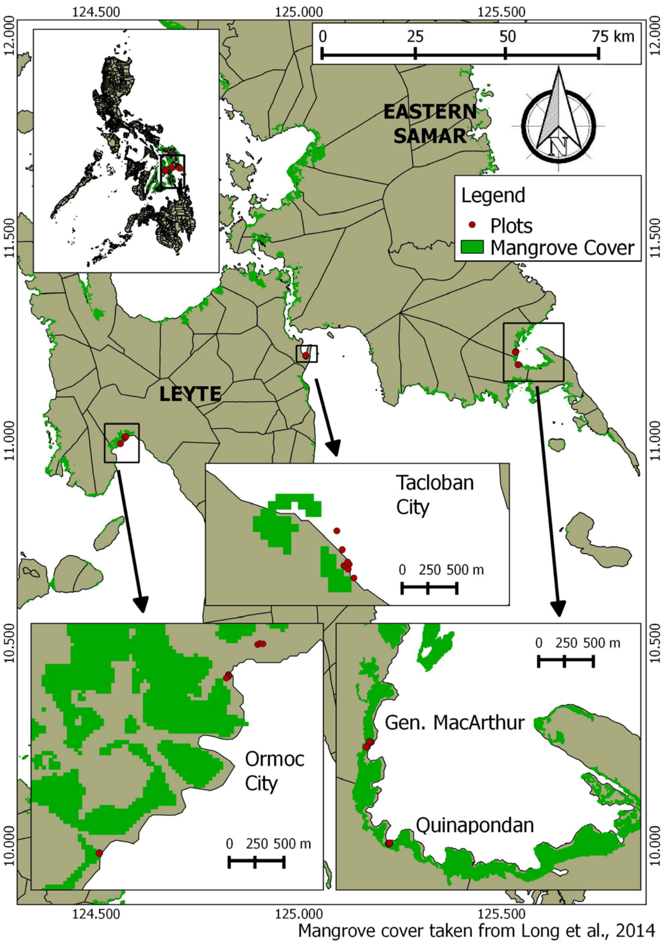

Figure 1. Map of the selected cities and municipalities as sampling sites of the study. Site selection considered the different geographical locations and the extent of mangrove area to cover the different characteristics of the mangrove sites of the region. Zoomed images indicate the location of the plots along the identified study sites (mangrove area taken from Long, Napton, Giri, & Graesser, 2014).

Thirty-six circular plots at 3-m radius were established on the selected Typhoon Haiyan-affected natural growth mangroves. The plots were situated in Tacloban City and Ormoc City in Leyte and, General MacArthur and

Quinapondan along the Matarinao Bay coastline in Eastern Samar (see Figure 1). The sites were selected according to their geographical location, mangrove cover extent and how they were affected by the impact of Haiyan. The plots were established haphazardly within the seafront areas. The study did not consider seafront areas near rivers to maintain similarity of sampling plots. At least eight plots were selected per municipality. Variations observed between sites may provide information pertinent for the restoration of mangrove ecosystems. Table 1 summarizes the basic information on the mangroves and on the physico-chemical characteristics of the study sites.

Table 1. Basic information on the mangrove forests of the study sites.

Site	Size (ha)[a]	No. of Plots	Salinity (%)	Typhoon Impact	Inundation (m)	Substrate
Tacloban	125	8	24 ± 1.58	Storm Surge	0.34 ± 0.06	Muddy
Ormoc	1,463	12	25 ± 2.17	Wind	0.51 ± 0.07	Muddy
Quinapondan	1,085	8	32 ± 2.21	Wind	0.42 ± 0.04	Muddy
Gen. MacArthur	425	8	30 ± 3.75	Wind	0.30 ± 0.10	Sandy- Muddy

[a] Long et al., 2014

Vegetation Resistance

In trees within the plot, circumference at breast height (CBH) and tree height (H) were measured. The CBH is then translated to its diameter at breast height (DBH) value assuming that the trunk cross-section is circular. The trees were identified through the mangrove identification guide by Primavera et al. (2004). Tree density per plot was also recorded. At least 30 mangrove trees belonging to the same genus across the sampling sites were tagged and used to determine vegetation resistance. Mangroves monitored with less than 30 tags were disregarded. Only mangroves with intact stem and root systems were tagged to capture pre-typhoon information from the said selected mangrove species.

The equation for determining the vegetation resistance (VR) was derived from Bayas et al. (2011), that is:

$$VR = H * DBH^2 * d \tag{1}$$

where *H* refers to the vegetation height (m), *DBH* (m) and, *d* corresponds to the vegetation density (number of individuals per hectare). The root systems were taken in consideration to measure *VR*. Similar to the trees, the prop roots and pneumatophores were counted as though they were individual plants. Thus, their respective diameters at ground level and heights were considered in the estimation of the root contribution to the *VR*.

Generating *VR* can determine the ability of mangroves belonging to a particular genus to resist wave impacts. The *VR* values only reflect the resistance of a collective group of trees belonging to the same genus in a given area. However, the estimation of *VR* values do not consider the drag from the sediments, which also contribute to reducing surge impacts (Zhang et al., 2012). The estimated *VR* values were aggregated according to genus in order to derive a genus-specific *VR*. Analysis of variance (ANOVA) was used to compare variations between sites and with respect to zonation within a given site. Prior to the ANOVA, normality and heterogeneity tests were done. Tukey's honestly significant difference (HSD) was used for post hoc test.

Seedling Recruitment and Growth

Seedling recruitment and growth rates are important in assessing the regeneration of an impacted mangrove ecosystem (Duke, 2001). Seedling density was monitored by counting the seedling recruits on the established 3-m radius plots, then converting the count into a per hectare unit.

Seedling growth was surveyed through counting of plastochron interval and measuring the seedling height. Analysis of seedling growth according to its genus was done by deriving the annual growth rate, further derived by multiplying the total number of internodes per year to the observed intermodal length. The recorded growth shall be the seedling regeneration potential (SRP) of a certain mangrove genus. Since the survey was done post-typhoon, we determined those seedlings that survived the impact of Typhoon Haiyan through the estimated time of internode formation as derived from Duarte et al. (1999) and Samson and Rollon (2008). Multiplying the number of internodes to the estimated number of days for the formation of one internode shall provide an estimate on how old the seedlings were. Seedlings with age estimates of at least 210 days were likely to have survived the impacts of Typhoon Haiyan and those aged less than 210 days were seedling recruits after the typhoon.

Variations of the tagged seedlings were assessed through ANOVA using the statistical software, R (R Core Team, 2014). Prior to ANOVA, heterogeneity and normality tests were done.

Results

Vegetation Resistance

Variations in the species composition were observed among the four mangrove sites. However, species belonging to the genus *Rhizophora* (n=135), *Sonneratia* (n=46), and *Avicennia* (n=177) dominated the mangrove stands of Leyte and Eastern Samar. Particularly, most of the seafront species identified were *Rhizophora apiculata, Sonneratia alba,* and *Avicennia marina*. Table 2 summarizes our estimates of the monitored height and DBH, and of the derived VR values.

The average density of the mangroves did not have a significant difference in the study sites. However, the average density of the mangroves in Quinapondan and General MacArthur was higher compared to those in Tacloban City and Ormoc City, but the difference is not significant. Mangrove heights were not significantly different across sites except in Quinapondan ($P<0.01$).
DBH values yielded significant differences in mangrove genus across all sites. *Rhizophora* species had lower DBH values than *Sonneratia* species in Quinapondan and General MacArthur (DBH= 0.116 ± 0.006 m and 0.140 ±

0.017 m, respectively). The DBH of *Rhizophora* species were likewise smaller than *Avicennia* species in Tacloban City, Ormoc City, and Quinapondan (DBH= 0.098 ± 0.004 m, 0.152 ± 0.035m, and 0.129 ± 0.015m, respectively).

Vegetation resistance values yielded significant differences among mangroves across the study sites. In Quinapondan and General MacArthur, the VR values of *Rhizophora* species (VR= 32± 9 cm^3 ha^{-1} and 70± 11 cm^3 ha^{-1}, respectively) were significantly lower as compared to *Sonneratia* species (VR= 342± 20 cm3 ha-1 and 372± 118 cm^3 ha^{-1}; $P< 0.01$ and $P < 0.05$, respectively). In Tacloban City and Ormoc City, VR values of *Rhizophora* species were significantly lower (VR= 34 ± 9 cm3 ha-1 and 129 ± 46 cm^3 ha^{-1}, respectively) as compared to *Avicennia* species (VR= 189 ± 49 cm^3 ha^{-1} and 655 ± 258 cm3 ha-1; $P < 0.05$ and $P < 0.01$, respectively).

Regeneration Potential

Accounts from key informants from all the municipalities revealed that total defoliation of mangroves occurred immediately after the impact of Typhoon Haiyan. The rate of refoliation was noted to be faster in denser, more intact mangroves as compared to mangroves with smaller vegetation cover. Figure 2 illustrates the different conditions of mangrove stands across all the study sites.

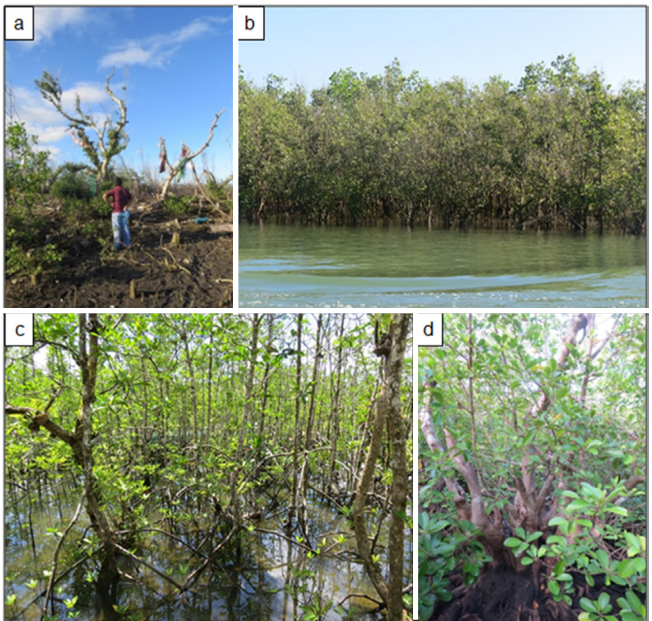

Figure 2. Condition of the mangroves in the study sites six months after Typhoon Haiyan (Yolanda): (a) the mangroves of Tacloban were badly damaged; (b) Ormoc mangroves having intact stand showing refoliation; and (c) Quinapondan and (d) General MacArthur having recovered mangrove stands.

Table 2. The average density, tree height, DBH and VR of selected seafront mangrove genus for every study site. Results show that VR values of *Rhizophora* are lower compared to that of *Sonneratia* and *Avicennia* species, across all sites. Superscript letters indicate significant differences from the Tukey HSD derived from ANOVA. The two variables that do not share the same superscript letter are significantly different statistically.

Mangrove Genus	Density (nha^{-1})	Height (m)	DBH (m)	VR (cm^3 ha^{-1})
		Tacloban City		
Rhizophora	2,986 ± 128	3.88 ± 0.23	0.048 ± 0.004^a	34 ± 9^a
Avicennia	2,925 ± 219	4.44 ± 0.69	0.098 ± 0.004^b	184 ± 48^b
Df	1	1	1	1
MS	975,882	0.7962	0.006557	57136
F	0.697	0.885	61.05	16.01
P	ns	ns	***	**
		Ormoc City		
Rhizophora	2,713 ± 279	8.43 ± 1.77	0.069 ± 0.014^a	129 ± 46^a
Avicennia	2,528 ± 425	10.63 ± 0.55	0.152 ± 0.035^b	655 ± 258^b
Df	1	1	1	1
MS	72,206	10.175	0.0146	580283
F	0.196	1.472	5.998	3.855
P	ns	ns	*	*
		Quinapondan		
Rhizophora	3,229 ± 441	4.07 ± 0.52^a	0.045 ± 0.006^a	32 ± 9^a
Sonneratia	3,539 ± 478	7.54 ±	0.116 ± 0.006^b	342 ± 20^b
Avicennia	3,539 ± 518	1.16^b	0.129 ± 0.015^b	372 ± 48^{ab}
Df	2	7.42 ±	2	2
MS	191,691	1.20^{ab}	0.011048	201517
F	0.096	2	0.096	8.181
P	ns	23.685	**	**
		5.828		
		*		
		General MacArthur		
Rhizophora	3,438 ± 480	4.64 ± 0.31	0.069 ± 0.0008^a	70 ± 11^a
Sonnerati	3,303 ± 236	5.40 ± 0.59	0.140 ± 0.017^b	372 ± 118^b
Df	1	1	1	1
MS	3,849	1.2267	0.0106	191649
F	0.03	1.642	18.02	17.3
P	ns	ns	**	**

Abbreviations. DF=degrees of freedom, MS=mean of squares, F=F value; P=P value;
***$P < 0.001$, **$P < 0.01$, *$P < 0.05$

The Tacloban mangroves (Figure 2a) were severely affected by Haiyan. Six months post-typhoon, the planted *Rhizophora* stands remain defoliated, indicating two possibilities: dead vegetation or delayed mortality. However, natural stands behind the *Rhizophora* zone dominated either by *Sonneratia* or *Avicennia* species withstood the typhoon impact. Moreover, these *Sonneratia* or *Avicennia* species exhibited refoliation and coppice on broken stems and trunks, indicating signs of recovery after the typhoon impact. In Ormoc (Figure 2b), Quinapondan (Figure 2c), and General MacArthur (Figure 2d), signs of vegetation regrowth were visible through refoliation. The coppice of existing mangrove stands, particularly on the *Sonneratia* and *Avicennia* species for the dominant mangrove stands, provide further evidence of regrowth. Among the study sites, the mangroves of Quinapondan and General MacArthur along the Matarinao Bay coastline exhibited faster vegetation regrowth.

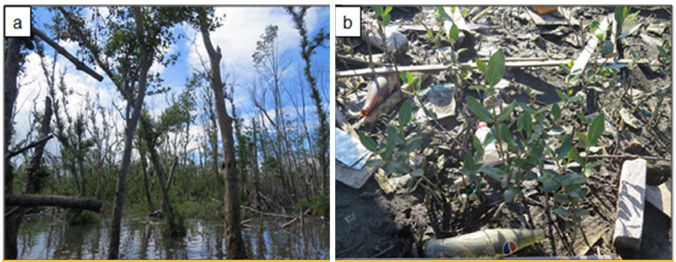

Figure 3. Images of mangrove regrowth indicators within species with (a) *Sonneratia* and *Avicennia* species showing leaf refoliation and coppice in Ormoc City. (b) In Tacloban, the visible seedling recruits were *Avicennia marina*.

Regrowth of affected mangroves appeared to be genus-specific as well. The *Rhizophora* species situated at the low elevation or foreshore area had higher mortalities as compared to the other mangrove species (see Figure 3a). Based on the refoliation, we surmised that a majority of the planted *Rhizophora* mangroves in Tacloban have not recovered. *Sonneratia* and *Avicennia* species, on the other hand, have started refoliating and coppicing six months post-Haiyan. Furthermore, we have observed site-dependent seedling recruitment rates among different Haiyan-affected areas. The dominant seedling recruits were non-*Rhizophora* species. Particularly in Tacloban, we have verified that most of the seedling recruits were from the species *Avicennia marina*.

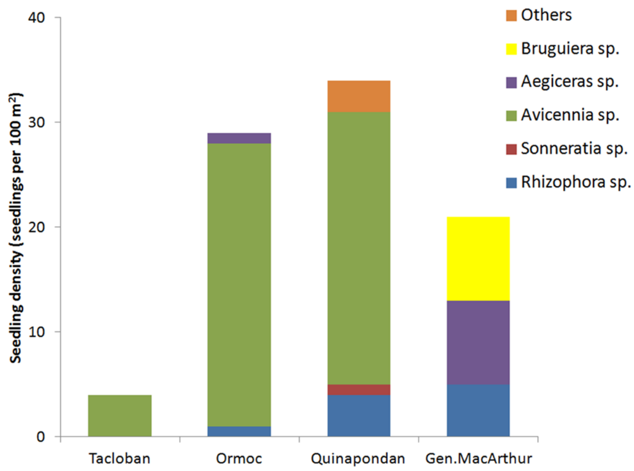

Figure 4. Seedling density of mangroves arranged according to genus type on all study sites. Seedling recruits showed the prevalence of *Avicennia* species across all sites except for Gen. MacArthur, which had a more diverse and even set of recruits. Letters above bars indicate significant differences based from Tukey HSD (*** P> 0.0001).

Seedling density showed that *Avicennia* species had the most seedling recruits six months after Typhoon Haiyan in Tacloban, Ormoc, and Quinapondan. Seedling recruits in General MacArthur showed diversity as it had seedling recruits of *Bruguiera* and *Aegiceras* species. *Sonneratia* species had one seedling recruit recorded in Quinapondan. Figure 4 summarizes the seedling density six months after Typhoon Haiyan.

There were 31 and 159 tagged seedlings for *Rhizophora*, and *Avicennia*, respectively. *Sonneratia* seedlings were not included due to the lack of seedlings present in the plots. Of the 190 tagged seedlings, 30 or 18% survived the typhoon impacts. Their survival may be due to the number of their internodes which roughly indicates the age of the seedlings.

The annual vertical growth rate of the seedlings was at 32.46 ± 4.64 cmyr-1 and 67.27 ± 2.62 cmyr-1 for *Rhizophora* and *Avicennia,* respectively ($P < 0.001$). Figure 5 provides a visual comparison of the said measurements.

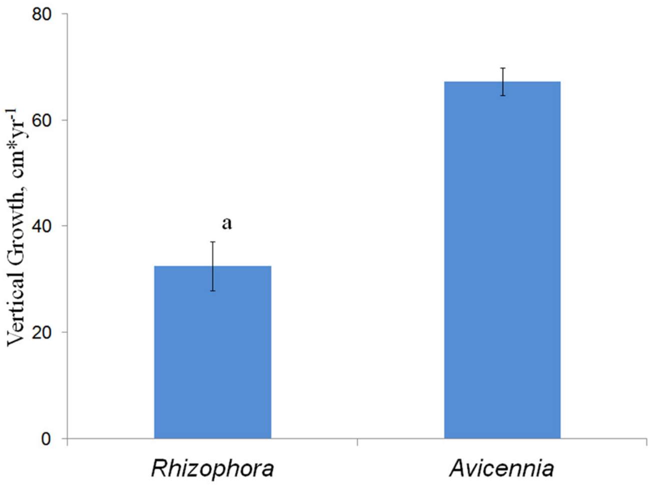

Figure 5. Estimated SRP of *Rhizophora* and *Avicennia* species through annual vertical growth. Letters above the bars indicate Tukey's HSD among *Rhizophora,* and *Avicennia*, with *Avicennia* having a longer annual vertical growth. Error bars represent growth differences among the tagged seedlings. Bars with different letters are significantly different based on Tukey HSD tests (***P< 0.001).

Discussion

Resiliency of Mangroves

This study has shown that *Sonneratia* and *Avicennia* species are able to recuperate and regenerate six months after the typhoon. With *Sonneratia* and *Avicennia* being the natural colonizers on seafront areas (Primavera & Esteban, 2008; Samson & Rollon, 2008), it was expected that the seedling annual growth rate would be higher as compared to that of *Rhizophora* species. Observations on the seedling recruitment of the seafront areas have shown the same result. Comparing the findings of this study to the results from other literature, *Avicennia* species likewise have longer annual vertical growth than *Rhizophora* (see Table 3). This suggests the use of *Avicennia* species, particularly on the seafront areas where existing practices are focused on the use of *Rhizophora* species because of its ease and convenience in planting (Primavera & Esteban, 2008; Samson & Rollon, 2008; Walters et al., 2008).

Table 3. Documented annual growth rate classified according to mangrove genus situated at the seafront. *Avicennia* species have longer vertical growth as compared to *Rhizophora*.

Location	Annual Growth ($cm\ yr^{-1}$)	Remarks	Source
Rhizophora spp.		typhoon-affected	this study
Leyte and Eastern Samar, Philippines	32.46		
Tayabas Bay, Philippines	35	low intertidal, planted stands	Samson and Rollon, 2008
Oyster Bay, Palawan, Philippines	7.08	natural growth	Padilla, Fortes, Duarte, Terrados, & Kamp-Nielsen, 2004
Buenavista, Palawan, Philippines	11.97	natural growth	Padilla et al., 2004
Ulugan Bay, Palawan, Philippines	6.16	natural growth	Padilla et al., 2004
Panama	15.65	oil spill	Duke and Pinzón, 1992
Panama	5.67		Duke and Pinzón, 1992
Nakhon Si Thammarat, Thailand	32.76	oil spill, shaded	Duarte et al., 1999
Avicennia spp.			this study
Leyte and Eastern Samar, Philippines	67.27	typhoon-affected	
Nakhon Si Thammarat, Thailand	140.4		Duarte et al., 1999

Aside from the seedling observations, the mangrove tree stands also showed larger growth in terms of height and DBH. Based on a mathematical relation between VR (equation 1), an increase in height, DBH or density consequently leads to an increase in VR value. VR increases the fastest with DBH (Bayas et al., 2011). Given the direct relationship of height and DBH to resisting external forces brought about by wind (Peltola, Kellomaki, Hassinen, & Granander, 2000) and water (Bayas et al., 2011), the ability of a tree to resist wave impact is therefore dependent on the size of a tree through its height and/or DBH. Moreover, optimal abiotic conditions for growth are related to the location of the mangrove at the intertidal zone through stressor gradients. The results support the hypothesis that *Sonneratia* and *Avicennia* species are highly suited for the seafront region. Consequently, tree growths of the said species are optimal, leading to their high VR six months post-typhoon.

The VR values further established the relevance of *Sonneratia* and *Avicennia* species as resilient mangroves. The higher VR values of tagged *Sonneratia* and *Avicennia* species along the coastline indicate the ability to withstand stronger wave impacts brought about by storm surges. The implied sturdiness of high VR in turn increases the likelihood of minimizing infrastructural and property damage behind the mangrove zone. Comparatively, in terms of VR, *Rhizophora* stands showed sturdiness within the range between rice plantations and shrubs. On the contrary, *Sonneratia* and *Avicennia* stands are sturdier than coconut plantations (see Table 4).

Table 4. Vegetation resistance coefficient values comparing the mangroves to other land cover types (adapted from Laso Bayas et al., 2011). The *Sonneratia* and *Avicennia* stands had VR values that are higher than coconut plantations, making them ideal greenbelts along coastlines. Estimated planting density is based from field observations, averaged throughout the entire study sites.

Land Cover Type	Est. Planting Density (stems ha^{-1})	Veg. Resistance ($m^3\ ha^{-1}$)
Cleared Land	0	0
River	0	0
Vegetable Plantations	31,250	13
Grassland	2,000,000	15
Rice Field	2,000,000	15
Rhizophora stands	3,103	49
Shrub	4,445	150
Coconut Plantation	156	281
Avicennia stands	2,915	320
Sonneratia stands	2,915	331
Agroforest	625	844
Forest	494	2,099
Settlements	n/a	3,538

The density, DBH and height were derived from values of the said variables from the sampling plots.

It should be noted that the *Rhizophora* stands were situated at the seafront area where it is likely not their optimal living conditions (Kitaya et al., 2002; Smith III, 1987). Low VR implies that the seafront areas may not promote the optimal growth of *Rhizophora* species. Colonies of *Rhizophora* growing on a more suitable site, may be expected to have greater height and DBH (Juanico & Salmo III, 2014; Salmo III & Juanico, 2015), and in turn greater VR values.

Although the VR values were pooled by genera in the present study, it is possible to estimate a multi-species VR for a given site. A multi-species VR may provide a more accurate explanation to why some sites receive better vegetal protection than others. Due to the limitations of our approach, we assume that the VR of the entire mangrove site is best represented by its totality.

Implications on Mangrove Rehabilitation and Management Practices

The capacity of a mangrove forest to deliver its ecosystem function depends on the rate of mangrove regeneration of denuded or typhoon-affected areas. Designed to brace these disturbances, they also have the capability to recuperate. However, there is a tendency for humans to attempt to assist this recuperation. Since typhoon damages are heterogeneous in nature (Sherman et al., 2001), ideally, we should first observe the natural regeneration rather than do immediate human interventions such as replanting (Lewis, 2005). Natural occurrence of seedlings is an excellent indicator of regeneration (Bosire et al., 2008) and its density reflect the extent of mangrove recovery as attributed to its corresponding physico-chemical environment (Mckee, 1995).

The findings of this study suggest the need for careful selection of species for rehabilitation purposes. The usual choice, *Rhizophora*, is generally not suitable for seafront areas due to its hampered ability to regrow (Primavera & Esteban, 2008). Optimal growth of these mangroves is not attained, as evidenced by a larger number of recorded mortalities, slow refoliation rate, and slower rate of seedling recruitment. Hence, current planting practices must be reconsidered. Instead, *Sonneratia* and *Avicennia* species are shown here to be more appropriate for seafront areas wherein these species remain to grow at optimal rates.

Conclusions

Sonneratia alba and *Avicennia marina* have high refoliation and coppicing potential. Further, *Avicennia marina* has high SRP thus making it the better contender for planting along seafront areas. The higher rate of natural regeneration of both genera implied that seedlings were successfully recruited because of their suitability to the abiotic conditions prevailing at the seafront areas. Further, the VR reinforces the suitability of these species as tolerant to strong wave impacts thereby making them resilient species, able to withstand typhoons at the seafront area. While this case is true for most mangrove ecosystems in the region, there should be caution in implementing rehabilitation activities. We would later use the findings presented in this paper to formulate and explore strategies for mangrove rehabilitation toward the development of coastal bio-shields.

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