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ASSESSING THE IMPACT OF BOARDWALKS TO GASTROPOD DIVERSITY IN SELECTED MANGROVES OF SOUTHERN LUZON AND MINDORO, PHILIPPINES

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Abstract: Gastropods have a wide range of habitats, including mangrove forests. However, they are also vulnerable to natural and anthropogenic disturbances both large- and fine-scale. This study examined the variation in gastropod diversity between the boardwalk and non-boardwalk sites in selected mangrove forests in the islands of Luzon and Mindoro, Philippines. Using a modified Beyond–Before-After-Control-Impact (BACI) design, 25 m^2 quadrats per 100 m were established parallel to the boardwalk, and in two control locations at least 200 m away. Epifaunal and infaunal gastropods were sampled through direct hand search and sediment collection. Air temperature, relative humidity, canopy cover, tree diameter, number of saplings and trees, electrical conductivity, organic matter, and pH were measured. A total of 43 gastropod species belonging to 18 families were identified. Diversity indices did not show a clear pattern that would prove fine-scale disturbance due to the boardwalk construction. There was no consistent significant difference in gastropod assemblages between boardwalk and control sites. This study provided evidence that boardwalks may have no clear apparent long-term negative impact on gastropod community in the sampled tropical mangrove ecosystems.

Keywords: boardwalk, diversity, gastropods, Luzon, mangroves, Mindoro

Introduction:

Mangrove ecosystems play important ecological and socio-economic roles. They prevent coastal erosion and reduce damages from waves, storm surges, and tsunamis (Spalding et al. 2014). Mangrove forests are also habitats for a diverse range of terrestrial and aquatic fauna. It is known to serve as nursery grounds for species of reef fish juveniles (Mumby et al. 2004; Abu El-Regal and Ibrahim 2014) and shrimp (Primavera 1997) and nesting grounds for species of birds (Garcia et al. 2013). Moreover, mangrove ecosystems are valued for their provisioning services including fisheries, timber, and non-timber forest products as well as cultural services like ecotourism and recreation

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(Uddin et al. 2013; Mukherjee et al. 2014). Despite these ecosystem services, mangroves have suffered extensive declines primarily caused by anthropogenic activities (Thomas et al. 2017).

Mangroves are among the most threatened ecosystems in the world. In fact, 38% of global mangrove area was lost in the period of 2000 to 2010 because of anthropogenic degradation (Thomas et al. 2017). Additionally, Southeast Asia lost 2% or 100,000 ha of mangrove area from 2000 to 2012 dominantly due to the conversion of mangrove forests into aquaculture facilities, agricultural lands, and palm oil plantations (Richards and Friess 2015). It is projected in the future that anthropogenic activities namely aquaculture, unrestricted logging, and overexploitation of fisheries will continue to be among the greatest threats to mangrove ecosystems (Alongi 2002).

Mangrove habitat loss and degradation affect a wide array of fauna including gastropods which are typically one of the abundant and most conspicuous macrofauna in mangrove systems (Hasidu et al. 2020; Bagarinao 2021). They are mostly valued ecologically for their role in leaf litter decomposition and nutrient cycling in mangrove forests (Fratini et al. 2004; Teoh et al. 2018). Economically, some species are harvested for food, lime production and medicinal purposes (Swadling 1994; Dey 2008; Zaman and Jahan 2015). However, studies conducted in Australian mangrove forests, particularly in New South Wales (Kelaher et al. 1998; Ross 2006) and Queensland (Skilleter and Warren 2000), showed that even fine-scale habitat modifications like trampling and boardwalk construction cause negative effects on the diversity and density of these animals.

In the Philippines, boardwalks may be found in numerous mangrove forests yet studies assessing its impact specifically on gastropods have not been conducted. To fill this research gap, the effect of boardwalk construction on gastropod biodiversity in three Philippine mangrove forests were determined. Specifically, this study aimed to analyze the gastropod community assemblage in sites distant and adjacent to constructed boardwalks.

Materials and methods:

Study area

The study was conducted in three tropical mangrove forests in Luzon and Mindoro Islands in the Philippines wherein boardwalk is present. These were Silonay Mangrove Conservation Area and Ecotourism Park, Calatagan Mangrove Forest Conservation Park, and Pagbilao Mangrove Experimental Forest (Fig. 1, Annexes).

Silonay Mangrove Conservation Area and Ecotourism Park in Barangay Silonay, Calapan City, Oriental Mindoro is a 42 ha locally managed Marine Protected Area (LMMPA). The Ecotourism Park is managed by Sama-samang Nagkakaisang Pamayanan ng Silonay (SNPS). It has a 400 m wooden boardwalk that is used in mangrove boardwalk tours facilitated by SNPS. Calatagan Mangrove Forest Conservation Park is located in Barangay Quilitisan, Calatagan, Batangas Province, Luzon Island. This 7.5-ha nature park is also an LMMPA, and it is managed by Pro-Mangrove Alliance and Implementing Team in Arms as Quilitisan’s Advocates of Nature (PALITAKAN). A 150 m wooden boardwalk and a watch tower were constructed on one of the two islets of the nature park in 2009. These were also constructed under the assistance of Conservation International – Philippines. In October 2017, approximately 80 m of the boardwalk was renovated into concrete. Three nipa huts and a mini pavilion have also been constructed aside from the boardwalk and watch tower. Lastly, Pagbilao Mangrove Experimental Forest is located in Barangay Ibabang Palsabangon, Pagbilao, Quezon Province, Luzon Island. The area is a 145 ha experimental forest managed by the Department of Environment and Natural Resources and it has an 800 m concrete boardwalk and an observation deck.

Sampling protocol

The sampling design used in this study is a modified Beyond-Before-After-Control-Impact (BACI) design adapted from Skilleter and Warren (2000). Quadrats were set up depending on the length of the boardwalk. One 5x5 m (25 m^2) quadrat per 100 m transect were randomly set up 1-5 m parallel to the boardwalk (Fig. 2). Two reference locations were established at least 700 m away from the belt transect to determine whether the habitat modifications affect the gastropod assemblages. The reference locations were parallel to the habitat modification. One quadrat 5x5 m (25 m^2) was also set up and sampled per 100 m transect. It was ensured that all quadrats were at least 10 m away from each other to prevent pseudoreplication.

Figure no. 2 Diagram of the modified Beyond Before-After-Control-Impact (BACI) design used in this study (modified from Skilleter and Warren 2000).

Measurement and determination of environmental variable

Environmental variables were measured prior to the sampling of gastropods. Forest canopy cover was estimated using a concave spherical densiometer (Forest Suppliers, Inc., USA) while the air temperature and relative humidity were measured using a digital thermometer (Uni-T, Model UT333, China). The number of saplings along with the number and diameter at breast height (DBH) of trees were also determined. Mangrove trees within quadrats were identified using Field Guide to Philippine Mangroves (Primavera 2009).

Soil samples were acquired from five random points within each 25 m^2 quadrat. Sedimentary characteristics including pH, electrical conductivity, and organic matter were analyzed in the laboratory. The soil samples were air-dried and sieved using a 1 mm sieve before analysis. Soil pH and electrical conductivity were determined in 1:5 soil-to-water suspension using a pH meter (Milwaukee pH tester, USA) and multiparameter water meter (YSI MPS 556: Handheld Multi-Probe Meter, USA), respectively. Soil organic matter was measured using the loss on ignition method (LOI). Around 10 g of air-dried soil samples were further dried in an oven at 100°C for 6 hours. Organic matter was combusted in a muffle furnace (Thermolyne 48000, USA) at 550°C for 8 hours. Soil organic matter (SOM) was then calculated using the following equation:

$$\text{SOM } (\%) = \frac{(DW_{100} - DW_{550})}{DW_{100}} \times 100$$

where DW_{100} and DW_{550} correspond to the dry weight of a soil sample at 100°C and 550°C, respectively.

Gastropod sampling and identification

Direct hand search was employed in sampling epifaunal gastropods. Epifaunal gastropods include individuals that were found on mangrove roots, stems and leaves at a height of 1 m above the ground within each quadrat. Thirty minutes sampling effort per person was allotted for searching live snails and empty shells on each quadrat. Sediments were also sampled at five random points in each quadrat for infaunal gastropods. The sediments were dry-sieved using a cascade system of 5, 3- and 1-mm metal sieves. The epifaunal and infaunal gastropods that had been sampled were brought to the Malacology Laboratory, Animal Biology Division, Institute of Biological Sciences, University of the Philippines Los Baños for identification and photography. Mangrove - associated gastropods were identified using published literatures (Springsteen and Leobrera 1986; Poppe 2008).

Data analysis

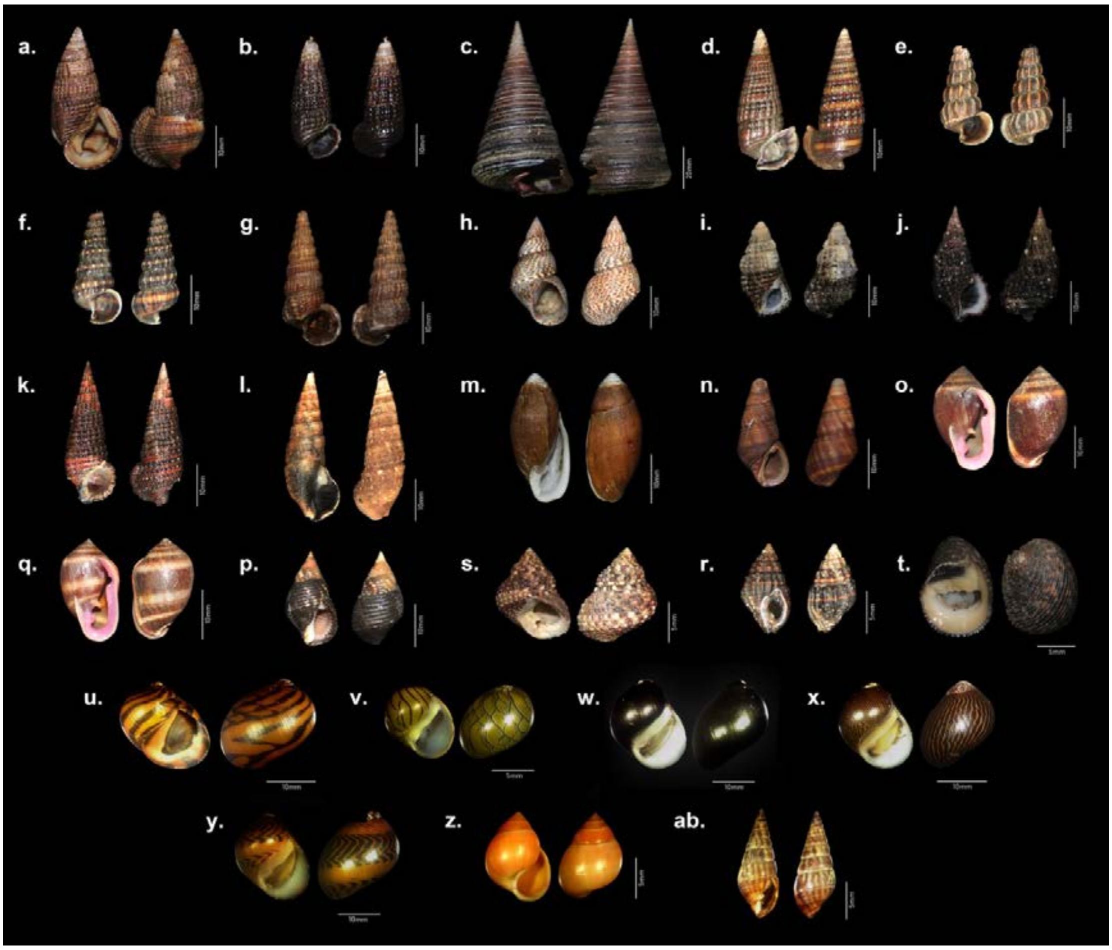
All quantitative data were tested for normal distribution and homogeneity of variance using one-sample Kolmogorov-Smirnov Test and Levene's Test for Homogeneity of Variance, respectively. Two-way analysis of variance (ANOVA) with Tukey post hoc test was used to determine significant difference in gastropod species richness and abundance across habitat conditions (control vs. boardwalk) and the three-sampling locations. Species richness is the total number of species per quadrat while abundance is the number of individuals of species per quadrat. To achieve normality species richness and abundance data were transformed using the formula, log (x+1) (Chiba 2007). All parametric statistical tests were performed using Statistical Package for Social Sciences (SPSS) for Windows (version 18, SPSS, Chicago, Illinois, USA). Species diversity and evenness were calculated using Shannon-Wiener Index of Diversity (Shannon and Weaver 1949), and species evenness (Simpson 1949), respectively. Species accumulation curve (SAC) was also generated to determine the total number of species during the process of data collection as additional individuals or sampling units accumulate. SAC was also used to evaluate the type of community assemblage pattern (whether α or β -dominated). Both individual-based and sample-based (quadrats) SAC were used. The completeness ratio (CR) was computed to determine the sampling efficiency derived from sample-based SAC. The EstimateS 9.1.0 (Colwell 2006) was used for all the SAC analyses. Finally, community assemblage similarity, based on Bray-Curtis distance matrices, was assessed by using analysis of similarity (ANOSIM) and permutational multivariate analysis of variance (PERMANOVA), while Similarity Percentages (SIMPER) was used to determine which species mainly contributed to the in-group similarities and between-group dissimilarities. ANOSIM and SIMPER were performed using Paleontological Statistics version 3.14 (Hammer et al. 2001). PERMANOVA was performed using Primer version 6 (Clarke and Gorley 2006).

Results and discussion:

Characteristic of Sampling Sites

A total of 13 mangrove species were identified across the sampling sites (Fig. 3). They belong to six families, namely, Acanthaceae (four species), Acrostichaceae (one species), Lythraceae (one species). The most number of mangrove species was in Pagbilao with ten, followed by Calapan with five species and Calatagan with four species. These are lower than the number of species published for each site (Alcanices 2017; Cudiamat and Rodriguez 2017; Moreno et al. 2018) primarily due to the difference in sample size.

Figure no. 3 Shells of gastropods collected from three sampled mangrove forests with boardwalk. a) *Terebralia sulcata*; b) *Pirenella incisa*; c) *Telescopium telescopium*; d) *Pirenella alata*; e) *Cerithidea decollata*; f) *Cerithidea balteata*; g) *Cerithidea quoyii*; h) *Littoraria scabra*; i) *Clypeomorus bifasciata*; j) *Clypeomorus pellucida*; k) *Cerithium coralium*; l) *Batillaria zonalis*; m) *Ellobium aurisjudae*; n) *Fissilabia decollata*; o) *Cassidula aurisfelis*; p) *Cassidula nucleus*; q) *Planaxis sulcatus*; r) *Nassarius niger*; s) *Monodonta labio*; t) *Nerita planospira*; u) *Neritodryas dubia*; v) *Clithon oualaniense*; w) *Vittina jovis*; x) *Vittina coromandeliana*; y) *Vittina waigiensis*; z) *Assiminea nitida*; ab) *Otopleura mitralis*



For Calapan boardwalk, the soil was slightly acidic to slightly alkaline with a pH level ranging from 6.80 – 7.50 and was non-saline to slightly saline having an electrical conductivity of 1.10 – 2.62 dS/m. Soil organic matter ranged from 4.30% – 5.71% (Tab. 1).

The canopy cover was 54.13%– 87.49% with the number of trees ranging from 3 – 8 having a diameter of 108.80 – 163.90 cm, while the sapling count varied from 14-33. The first control site had slightly acidic to slightly alkaline soil with a pH level ranging from 6.20 – 7.09 and was slightly saline to moderately saline having an electrical conductivity ranging from 2.06 – 4.47 dS/m. Soil organic matter ranged from 4.68% – 6.88%. The canopy cover ranged from 79.15% – 89.58% with the number of trees ranging from 3-9 having a diameter of 74.50 –123.70 cm, while the sapling count varied from 7-33. Second control site featured slightly acidic to neutral soil with a pH level ranging from 6.30 – 6.50 and was slightly saline to moderately saline having an electrical conductivity ranging from 2.06 – 4.74 dS/m. Soil organic matter ranged from 6.41% – 8.21%. The canopy cover ranged from 54.13% – 91.66% with number of trees ranging from 4 – 12 with a diameter of 98.10 – 214.20 while sapling count varied from 6 – 36.

Table no. 1 Physicochemical variables across the three sampled mangrove forests with boardwalk

Site	SOM (%)	pH	SEC (ds/m)	RH (%)	AT (°C)	CC (%)	NS	NT	TD (cm)
Calapan									
Boardwalk	4.72	7.08	2.10	76.38	29.20	73.73	23.75	5.50	124.43
Control 1	5.77	6.65	3.22	74.70	28.90	86.30	14.25	6.00	99.78
Control 2	7.22	5.68	4.04	75.55	28.90	78.38	16.25	6.75	164.93
Calatagan									
Boardwalk	16.28	8.54	5.08	85.05	27.20	83.30	11.00	8.50	158.75
Control 1	12.62	8.52	5.88	84.90	27.75	90.60	7.50	8.00	190.05
Control 2	15.51	8.30	5.43	85.10	27.85	95.85	2.50	8.50	198.05
Pagbilao									
Boardwalk	22.41	6.25	4.78	85.69	26.98	84.86	6.50	14.38	208.64
Control 1	21.40	6.26	3.63	85.90	28.09	86.84	5.75	12.38	188.35
Control 2	22.91	6.33	5.85	86.06	27.96	88.89	12.63	14.38	256.28

Note: SOM-Soil organic matter; pH-Soil pH; SEC-Soil electrical conductivity; RH-Relative humidity; AT-Air temperature; CC-Canopy cover; NS-Number of saplings; NT-Number of trees; TD-Tree diameter at DBH

The Calatagan boardwalk featured a moderately alkaline soil with a pH level ranging from 8.32 – 8.75 and was moderately saline with an electrical conductivity ranging from 4.87 – 5.30 dS/m. Soil organic matter ranged from 16.24% –16.31%. The canopy cover in this area was 77% –89.58% with the number of trees ranging from 6 – 11 with diameter of 132.10 – 185.42 cm while sapling count varied from 3 – 19. First control site revealed a moderately alkaline soil with a pH level ranging from 8.41 – 8.63 and was moderately saline with an electrical conductivity and 5.80 – 5.97 dS/m. Soil organic matter ranged from 9.77% – 15.46%. The canopy cover in this area was 87.49% – 93.70% with eight trees having a diameter of 187.96 – 192.10 cm while sapling count varied from 0-15. Second control site had a moderately alkaline soil with a pH level ranging from 8.20 – 8.40 and was moderately saline with an electrical conductivity ranging from 5.14 – 5.72 dS/m. Soil organic matter ranged from 10.08% – 20.94%. The canopy cover ranged from 93.75% – 97.92% with the number of trees ranging from 8-9 with diameter of 198.04 – 198.12 cm, while sapling count varied from 2-3. The boardwalk area in Pagbilao mangrove forest had slightly acidic to slightly alkaline soil with a pH level ranging from 5.90 – 7.30 and was slightly saline to moderately saline having an electrical conductivity of 1.10 – 2.62 dS/m. Soil organic matter ranged from 19.18% – 26.85%. The canopy cover for this area was 76.02% – 92.70% with the number of trees ranging from 8-24 with a diameter from 142.24– 296.70 cm while sapling count varied from 2-15. First control site had a strongly acidic to neutral soil with a pH level ranging from 5.40 – 6.80 and was non-saline saline to moderately saline with an electrical conductivity ranging from 1.70 – 5.14 dS/m. Soil organic cm. matter ranged from 16.05% –32.44%. The canopy cover was 79.20% – 95.83% with the number of trees ranging from 4-23 with a diameter of 97.59 – 292.10 cm, while sapling count varied from 0-14. Second control site had a slightly acidic to neutral soil with a pH level ranging from 6.00 – 7.20 and was moderately saline with an electrical conductivity ranging from 5.14 – 6.86 dS/m. Soil organic matter ranged from 15.28% – 28.99%. Canopy cover was 79.14% – 95.83% with number of trees ranging from 7 – 23 with diameter from 98.10 – 214.20 cm, while sapling count varied from 7-20.

Gastropod Diversity

A total of 5,929 individual mangrove snails were sampled in Calatagan, Calapan, and Pagbilao (Fig. 3; Tab. 2, Annexes). The sampled snails belonged to 43 species and 18 families. Among the three sites, Calatagan had the most numerous individual snail count (2938), followed by Calapan (2557), and Pagbilao (434). Calatagan also featured the most number of species (31) followed by Calapan and Pagbilao with 17 and eight species, respectively. Overall, Shannon-Wiener diversity index showed that Calapan (H′ = 1.92) was more diverse than Calatagan (H′ = 1.43) and Pagbilao (H′ = 1.41). Meanwhile, Pagbilao had the highest species evenness (J′ = 0.51), followed by Calapan (J′ = 0.40) and Calatagan (J′ = 0.14) (Tab. 3).

Table no. 3 Species diversity and evenness across the three Philippine mangrove ecosystems in Calatagan, Batangas, Calapan, Oriental Mindoro, and Pagbilao, Quezon

Sampling Site		NQ	H'^{a}	J'^{a}
Calatagan				
	Boardwalk	2	1.40	0.16
	Control 1	2	1.24	0.25
	Control 2	2	0.87	0.27
	Overall		1.43	0.14
Calapan				
	Boardwalk	4	1.42	0.38
	Control 1	4	1.78	0.59
	Control 2	4	1.80	0.55
	Overall		1.92	0.40
Pagbilao				
	Boardwalk	8	0.90	0.62
	Control 1	8	1.32	0.74
	Control 2	8	1.27	0.45
	Overall		1.41	0.51
Overall				
	Boardwalk	14	2.16	0.25
	Control 1	14	1.96	0.27
	Control 2	14	2.26	0.46

Note: NQ-Number of Quadrats; H'^{a}-Shannon diversity index; J'^{a}-Species evenness

The diversity indices calculated within Calatagan showed that there was a higher diversity along the boardwalk (H′ = 1.40) than both of the control sites (H′ = 1.24, H′ = 0.87). In terms of species evenness, control sites were more even (J′ = 0.25, J′ = 0.27) than the boardwalk (J′ = 0.16). The most abundant species in Calatagan were *Terebralia sulcata* (1893) and *Clithon oualaniense* (350). Particularly, *C. oualaniense* was only found in control locations while *T. sulcata* was found along the boardwalk and control sites. Higher gastropod diversity and evenness were observed in the control sites in Calapan (H′ = 1.78, J′ = 0.59; H′ = 1.80, J′ = 0.55) than that sampled near the boardwalk (H′ = 1.42, J′ =

0.38). The most abundant species in Calapan were *Cerithidea balteata* (627) and *Vittina coromandeliana* (832). Both species were found along the boardwalk and control sites. In Pagbilao, one of the control sites (H′ = 1.32) was more diverse than the boardwalk (H′ = 1.27). However, only one of the control sites (J′ = 0.74) was more even than the sampled site near the boardwalk (J′ = 0.62). The most abundant species were *Cerithidea quoyii* (232) and *Cassidula nucleus* (83). Both species were found along the boardwalk and the reference locations.

Several gastropod species that were sampled in the boardwalk were not associated with mangrove ecosystems. These species include *Bulla vernicosa*, *Cypraea* sp., *Gibberulus gibberulus*, and *Parametria epamella*. These gastropod species are associated with coral reef habitats (Abbott 1959; Beu et al. 2012; Steger et al. 2017). They were possibly transported in mangrove area through hermit crabs or water currents (Zvonareva et al. 2015). Excluding these species from calculation resulted to nearly the same species number and Shannon-Wiener diversity indices across habitat conditions in the area.

Sample-based and individual-based species accumulation curves showed that the completeness ratio for all sites and habitat conditions was 0.70 (Fig. 4, Annexes). Accordingly, the control locations had the highest completeness ratio (CR = 0.89) while boardwalk had the lowest (CR = 0.49). It was shown that the gastropod assemblages found in boardwalk and non-boardwalk sites exhibited a β-dominated pattern characterized by gradual slopes and late asymptotes.

Comparison of Mangrove Snail Assemblages

Significant interaction was found between the effects of site and habitat condition on overall species richness ($p < 0.05$). Simple main effects analysis showed that species richness was significantly affected by site ($p < 0.05$) and not by habitat condition ($p = 0.371$) (Fig. 5, Annexes). These results showed that there was no significant difference in the species richness along the boardwalk and controls across the three sites. In terms of density, there was also a statistically significant interaction between the effects of site and habitat conditions. Simple main effects analysis showed that density was significantly affected by site ($p < 0.05$) and habitat condition ($p = 0.03$). One-way ANOVA results showed that the density of gastropods was not significantly different across the habitat conditions in Calatagan ($p = 0.119$) (Fig. 6, Annexes). Meanwhile, there was statistically significant difference among the habitat conditions ($p = 0.021$) in species richness. Tukey post hoc test further revealed that the species richness along the boardwalk was significantly higher ($p = 0.019$) than one of the controls (Control 2). In Calapan, the species richness was not considerably different across the habitat conditions ($p = 0.121$). In contrast, there was a significant difference in the density of mangrove gastropods across the habitat conditions ($p = 0.001$). Tukey post-hoc test highlighted that the density in the boardwalk was significantly lower ($p = 0.001$) than one of the control locations (Control 2). In Pagbilao, there was a significant difference in the density ($p = 0.004$) and species richness ($p = 0.001$) of gastropods across habitat conditions. The density and species richness along the boardwalk was significantly lower ($p < 0.05$) than one of the controls (Control 2). ANOSIM showed that the community assemblages across habitat conditions in Calatagan were similar (R = 0.44, $p = 0.1338$) and thus, there was no evidence of an impact altering the gastropod community (Tab. 4).

Table no. 4 Analysis of Similarity (ANOSIM) test for significant differences between habitat conditions

Sites	R	*p-value*	TQ (n)
Calatagan	0.44	0.1338	6
Calapan	0.60	0.0022	12
Pagbilao	0.65	0.0001	24
Overall	0.82	0.0001	42

Note: TQ-Total quadrats

Meanwhile, ANOSIM showed significant difference in the community assemblages across habitat conditions in Calapan (R = 0.60, p = 0.0022) and Pagbilao (R = 0.65, p = 0.0001). Most pairwise analyses were also significant ($p < 0.05$). Nevertheless, there was still no clear pattern that separated the sampled site along the boardwalk and the control locations. Particularly in Calapan, the gastropod assemblage along the boardwalk (CLB) was significantly different with control 1 (CLC1) but not with control 2 (CLC2). Meanwhile, CLC 2 was significantly different with CLC1. In Pagbilao, all sampled locations were significantly different with each other. Additionally, the overall average dissimilarity (Tab. 5) acquired using SIMPER was the highest between the two controls (94.90). The overall average dissimilarity should be higher in between the boardwalk (PB) and the two controls (PC1 and PC2). Hence, there was no clear evidence again that the boardwalk construction altered the gastropod assemblages in both Calapan and Pagbilao.

Table no. 5 Pairwise analysis (p values) of mangrove gastropod community assemblage based on Bray-Curtis Similarity among the habitat conditions per site.

Sites	CTB^a	CTC1^a	Sites	CLB^a	CLC1^a	Sites	PB^a	PC1^a
CTB			CLB			PB		
CTC1	0.33		CLC1	0.03		PC1	0.02	
CTC2	0.66	0.33	CLC2	0.06	0.03	PC2	0.01	0.00

Note: ^{a} CTB- Calatagan Boardwalk; CTC1- Calatagan Control 1; CTC2- Calatagan Control 2; CLB- Calapan Boardwalk; CLC1- Calapan Control 1; CLC2- Calapan Control 2; PB- Pagbilao Boardwalk; PC1- Pagbilao Control 1; PC2- Pagbilao Control 2

The similarity percentage analysis identified which species contributed to the average dissimilarity among habitat conditions in Calapan and Pagbilao (Tab. 6). In Calapan, *Cerithidea balteata* was found to contribute the most (30.23%) to the overall average dissimilarity between the boardwalk (CLB) and one of the controls (CLC1). *Vittina coromandeliana* contributed 32.29% of the overall average dissimilarity between the two controls (CLC1 vs. CLC2). Meanwhile, *Cerithidea quoyii* had the highest contribution to the overall average dissimilarities between habitat conditions in Pagbilao. Calatagan was excluded from this analysis because the ANOSIM test showed that there was no significant difference in gastropod assemblages across habitat conditions.

There was no consistent pattern in the diversity indices calculated between the boardwalk and control sites in the three Philippine mangrove ecosystems examined. In addition, a β- dominated pattern exhibited in this study shows that the infracommunity structure across the habitat conditions was isolationist characterized as individualistic and insensitive to the presence of other species (Dove and Cribb 2006), therefore more quadrats and individuals should be sampled to capture the total diversity. Possibly, the differences in the diversity indices may not be attributed directly to boardwalk construction. It could be inferred that the fine-scale anthropogenic habitat modification only caused pulse disturbance. Disturbances are classified according to their temporal pattern of impact intensity and duration. Pulse disturbances, as opposed to press disturbances, are short-term (Underwood et al. 2003). These disturbances include those that are common in nature such as hurricanes, bushfires, and oil spills (Lake 2011).

Table no. 6 Similarity percentage analysis of sites with significant difference in mangrove gastropod community assemblage

Sites[a]	OAD	Gastropod species	AD	C (%)	MAG1	MAG2
CLB vs. CLC1	72.52	*Cerithidea balteata*	21.92	30.23	58	30
CLC1 vs. CLC2	65.00	*Vittina coromandeliana*	20.99	32.29	60	146
PB vs. PC1	78.82	*Cerithidea quoyii*	27.99	35.51	15	0
PB vs. PC2	79.66	*Cerithidea quoyii*	35.84	45.00	15	19
PC1 vs. PC2	94.90	*Cerithidea quoyii*	42.87	45.17	0	19
Overall	91.65	*Terebralia sulcata*	19.90	21.71		

Note: [a] CLB- Calapan Boardwalk; CLC1- Calapan Control 1; CLC2- Calapan Control 2; PB- Pagbilao Boardwalk; PC1- Pagbilao Control 1; PC2- Pagbilao Control 2; OAD-Overall Average Dissimilarity; AD-Average Dissimilarity; C- Contribution; MAG1-Mean Abundance Group 1; MAG2-Mean Abundance Group 2

Boardwalk construction in the tropical mangroves might only be considered as a pulse disturbance because the boardwalks observed were originally constructed more than three years before the conduct of this study. Several researches have reported rapid recovery of gastropods after disturbances (Strayer et al. 1986; Fujioka et al. 2008). Strayer et al. (1986) documented rapid recovery of gastropod communities from forest disturbances that were much larger in scale such as land-use change (agroforestry), burning of trees, and clearcutting. Similarly, Fujioka et al. (2008) reported the recovery of epibenthic mangrove gastropods from the Indian Ocean Tsunami (IOT) in Ranong, Thailand within two years.

Mangrove rehabilitation may also be attributed to the possible recovery of gastropods from the initial disturbance caused by boardwalk construction. Rehabilitated mangroves were found to be effective in facilitating colonization of molluscan assemblages although relative to the recovery of vegetation and sediment conditions (Salmo and Duke 2010; Zvonareva et al. 2015; Salmo et al. 2019). Mangrove tree-planting activities may help in the restoration of gastropod communities by increasing forest cover and number of substrates for arboreal snails. Locals revealed that tree-planting activities involving multiple species of mangroves were mostly conducted along the boardwalk in the three sites. In Calatagan, the species that were used in tree-planting were from the genera *Avicennia*, *Rhizophora*, and *Sonneratia*. PALITAKAN has assisted a maximum of four tree-planting activities yearly. *Rhizophora apiculata* and *Rhizophora stylosa* were the species that are often planted in Pagbilao. Meanwhile, *Sonneratia alba* and *Avicennia* spp. were the more frequently utilized species for this activity in Calapan.

Species in Luzon (Calatagan and Pagbilao) were shown to be separated from the species in Mindoro (Calapan). In addition, most species were observed to cluster in Calatagan. Species richness and density was the highest in this sampling site. This may be due to the frequent inundation by marine tides (Cudiamat and Rodriguez 2017) that provides an increase in soil pH, salinity, and calcium availability (Peverill et al. 1999; Mitsch et al. 2009). Several species were also associated with the number of mangrove and *Nypa* saplings. These species include *Littoraria scabra*, *Vittina waigiensis*, *Vittina jovis*, and *Vittina coromandeliana*. *L. scabra* was highly correlated with the number of mangrove saplings because it is an arboreal snail (Zvonareva et al. 2015). *Vittina* spp. are also known to be correlated with *Nypa fruticans* saplings (Lozouet and Plaziat 2008). On the other hand, *Ellobium aurisjudae*, *Cerithidea quadrata*, and *Pirenella incisa* have no apparent relation with the measured environmental variables. This suggested that a single variable was not enough to explain their habitat preference among the sampling sites.

Conclusions:

Overall, this study suggests that boardwalk construction had no clear negative effects on gastropod community in the sampled tropical mangrove ecosystems thus, it may not be considered a press disturbance. It is possible that mangrove gastropods have already recovered from the pulse disturbance caused by the boardwalk construction. Mangrove rehabilitation may have also assisted the recovery of gastropod community through the increase in tree density and consequently, the surface area available for arboreal snails. This study also supports the continuous use of boardwalks as a major tool in linking conservation and recreation in Philippine mangrove systems, provided that mangrove forest cover is not significantly altered.

The use of Before-after-control-impact (BACI) designs is recommended in the evaluation of anthropogenic habitat modification in Philippine ecosystems. This includes the collection of data prior to the human-induced change. In the absence of this data, After- control-impact (ACI) designs may also be used as an alternative. Particularly for future impact assessments to be conducted in mangrove forests, comprehensive vegetation analysis is recommended to be conducted. Further studies on the ecological adaptations of mangrove snails are also suggested to aid the understanding of their distribution and recovery after disturbances. Lastly, it is recommended for similar studies to be conducted in other mangrove ecosystems in the country. Sampling more mangrove ecosystems with boardwalks will be helpful in achieving a higher completeness ratio.

Rezumat:

EVALUAREA IMPACTULUI TROTUARELOR ASUPRA DIVERSITĂȚII GASTEROPODELOR DIN ANUMITE MANGROVE ÎN SUDUL LUZONULUI ȘI MINDORO, FILIPINE

Gastropodele au o gamă largă de habitate, inclusiv pădurile de mangrove. Cu toate acestea, ele sunt, de asemenea, vulnerabile la perturbările naturale și antropice, atât la scară mare, cât și la scară mică. Acest studiu a examinat variația diversității gasteropodelor între siturile cu și fără trotuare din pădurile de mangrove selectate în insulele Luzon și Mindoro, Filipine. Utilizând un design modificat Beyond-Before-After-Control-Impact (BACI), au fost stabilite pătrate de 25 m^2 pe 100 m, în paralel cu trotuarul și în două locații de control aflate la cel puțin 200 m distanță. Gasteropodele epifaunale și infaunale au fost eșantionate prin cercetare manuală directă și prin colectarea sedimentelor. Au fost măsurate temperatura aerului, umiditatea relativă, acoperirea coronamentului, diametrul copacilor, numărul de puieți și de copaci, conductivitatea electrică, materia organică și pH-ul. În total, au fost identificate 43 de specii de gasteropode aparținând la 18 familii. Indicii de diversitate nu au arătat un model clar care să dovedească o perturbare la scară fină datorată construcției trotuarului. Nu a existat nicio diferență semnificativă constantă în ansamblurile de gasteropode între siturile de pe trotuar și cele de control. Acest studiu a furnizat dovezi că este posibil ca trotuarele să nu aibă un impact negativ clar și evident pe termen lung asupra comunității de gasteropode din ecosistemele de mangrove tropicale eșantionate.

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Annexes:

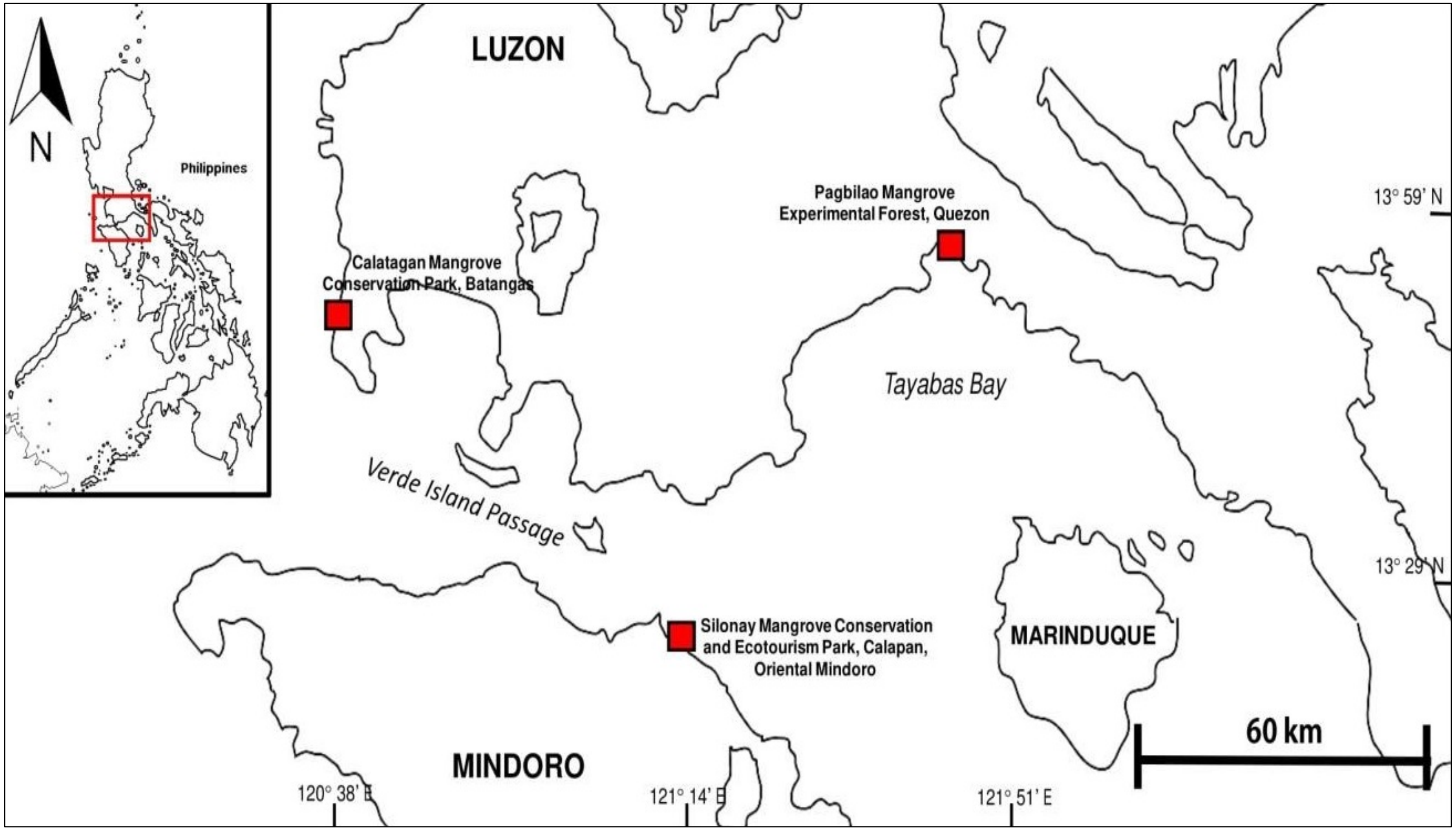

Figure no. 1 Location of the three mangrove forests with boardwalk in southern Luzon and Mindoro

Table no. 2 Diversity of gastropods across the three mangrove ecosystems in Calatagan, Batangas, Calapan, Oriental Mindoro, and Pagbilao, Quezon

Family and Species	Habitat	CBa	CPa	PQa	Total
Assimineidae					
Angustassiminea nitida (Pease, 1865)	BC	17	0	0	17
Batillaridae					
Batillaria zonalis (Bruguière, 1792)	C	17	0	0	17
Bullidae					
Bulla vernicosa (A. Gould, 1859)	B	2	0	0	2
Cerithiidae					
Cerithium coralium (Kiener, 1841)	BC	85	0	0	85
Clypeomorus bifasciata (G. B. Sowerby II, 1855)	BC	96	0	0	96
Clypeomorus pellucida (Hombron & Jacquinot, 1848)	BC	185	0	0	185
Columbellidae					
Parametaria epamella (Duclos, 1840)	B	1	0	0	1
Costellariidae					
Vexillum formosense (G. B. Sowerby III, 1889)	B	1	0	0	1
Cypraeidae					
Cypraea sp. (Linnaeus, 1758)	B	3	0	0	3
Ellobiidae					
Cassidula aurisfelis (Bruguière, 1789)	BC	34	0	9	43
Ellobium aurisjudae (Linnaeus, 1758)	BC	0	0	34	34
Melampus nuxcastaneus (Kuroda, 1949)	B	2	0	0	2
Cassidula nucleus nucleus (Gmelin, 1791)	BC	88	3	82	173
Littorinidae					
Littoraria scabra (Linnaeus, 1758)	BC	7	253	50	310
Muricidae					
Chicoreus capucinus (Lamarck, 1822)	BC	7	0	5	12
Nassariidae					
Nassarius coronatus (Bruguière, 1789)	B	1	0	0	1
Nassarius niger (Hombron & Jacquinot, 1848)	BC	28	0	0	28
Neritidae					
Clithon oualaniense (Lesson, 1831)	C	350	97	0	447
Nerita histrio (Linnaeus, 1758)	B	6	0	0	6
Nerita chamaeleon (Linnaeus, 1758)	B	1	0	0	1
Nerita planospira (Anton, 1838)	BC	66	0	8	74
Nerita signata (Lamarck, 1822)	B	5	0	0	5
Neritina sp. (Lamarck, 1816)	C	0	1	0	1
Neritodryas dubia (Gmelin, 1791)	C	0	6	0	6
Vittina coromandeliana (G. B. Sowerby I, 1836)	BC	0	832	0	832
Vittina jovis (Récluz, 1843)	C	0	136	0	136
Vittina waigiensis (Lesson, 1831)	BC	0	233	0	233
Planaxidae					
Planaxis sulcatus (Born, 1778)	B	1	0	0	1
Fissilabia decollata (Quoy & Gaimard, 1833)	BC	28	0	0	28
Potamididae					
Cerithidea balteata (A. Adams, 1855)	BC	0	627	0	627
Cerithidea decollata (Linnaeus, 1767)	BC	0	81	0	81
Cerithidea moerchii (A. Adams, 1855)	B	0	2	0	2
Cerithidea quadrata (Hombron & Jacquinot, 1848)	B	0	1	0	1
Cerithidea quoyii (Hombron & Jacquinot, 1848)	BC	1	265	232	258
Pirenella alata (Philippi, 1849)	B	0	2	0	2
Pirenella cingulata (Gmelin, 1791)	B	2	2	0	4
Pirenella incisa (Hombron & Jacquinot, 1848)	BC	0	193	0	193

Telescopium telescopium (Linnaeus, 1758)	B	1	0	2	3
Terebralia sulcata (Born, 1778)	BC	1893	63	14	1970
Pyramidellidae					
Otopleura mitralis (A. Adams, 1854)	C	6	0	0	6
Ranellidae					
Monoplex aquatilis (Reeve, 1844)	C	2	0	0	2
Strombidae					
Gibberulus gibberulus (Linnaeus, 1758)	B	1	0	0	1
Trochidae					
Monodonta labio (Linnaeus, 1758)	C	1	0	0	1
Total		2938	2557	434	5929

Note: B-Boardwalk; C-Control; BC-Boardwalk and Control; CB-Calatagan; CP-Calapan; PQ-Pagbilao

Figure no. 4 Sample (A) and individual-based (B) species accumulation curve in the two habitat conditions across the three sampling sites. High completeness ratio (CR) indicates effective sampling

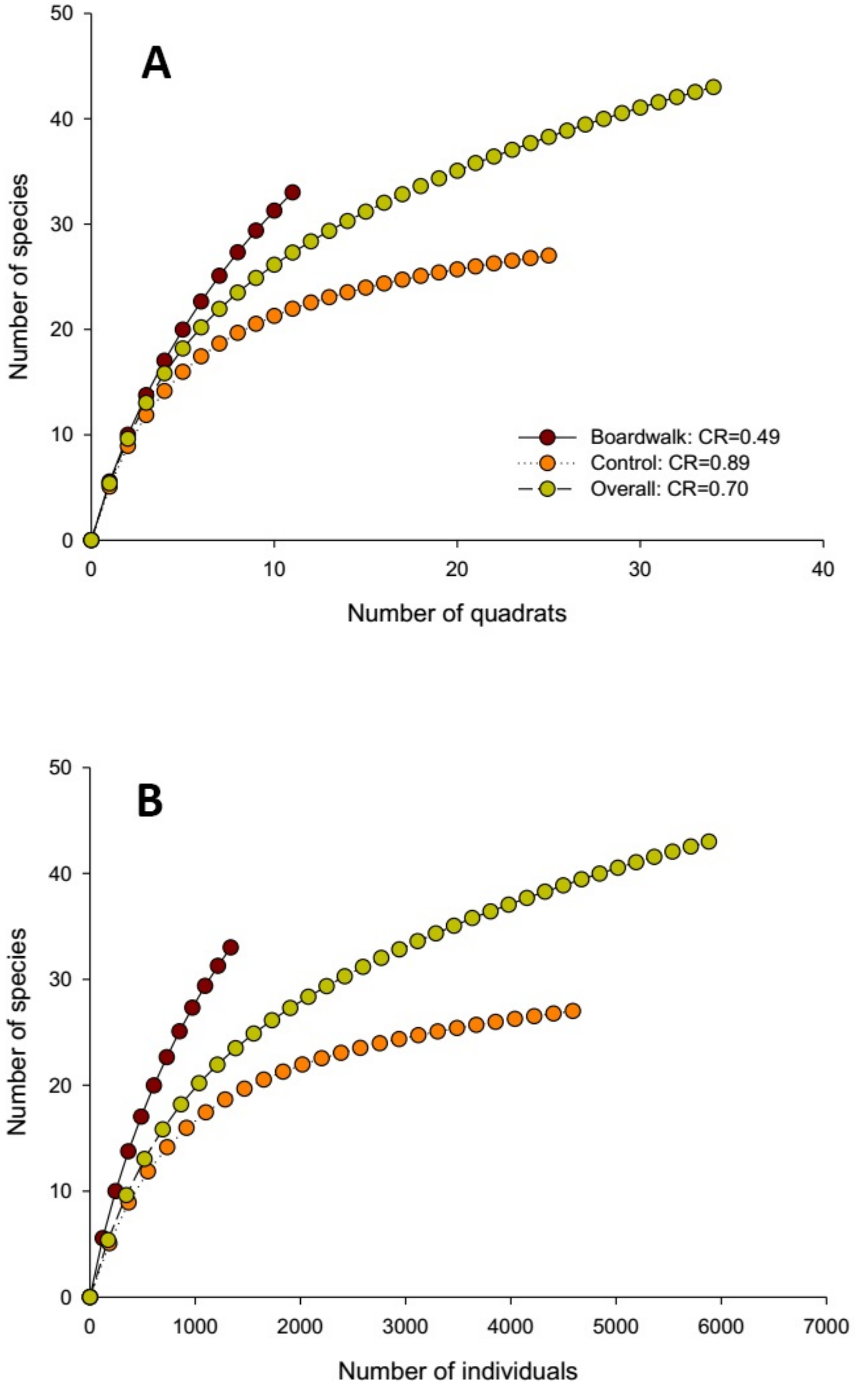

Figure no. 5 Species richness and abundance (mean ± SE) across the three Philippines mangrove ecosystems and habitat conditions. Consecutive different letters indicate significant difference at $p < 0.05$

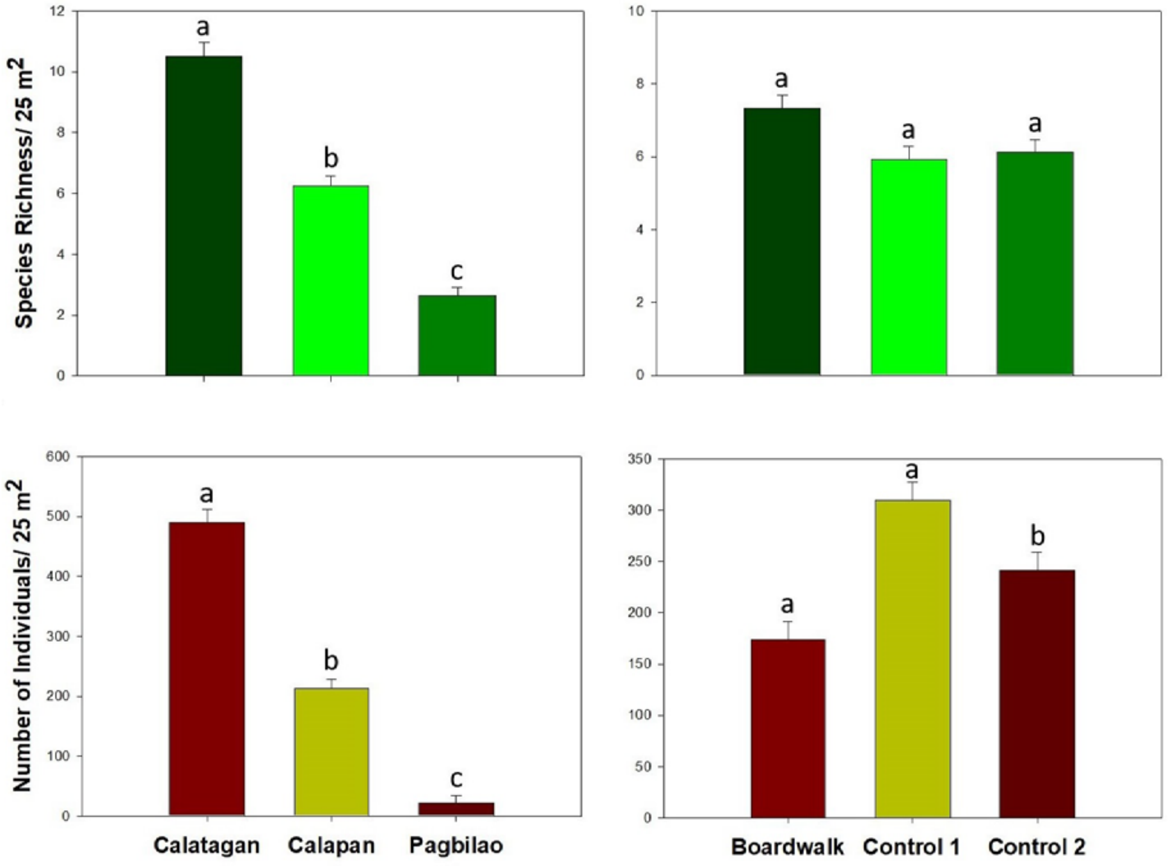

Figure no. 6 Species richness and abundance (mean ± SE) across habitat conditions in each of the Philippine mangrove ecosystems. Consecutive different letters indicate / are indicative of significant difference at *p* < 0.05