POTENTIAL IMPACTS ON SEAGRASS ECOSYSTEM IN MARIBOJOC BAY, BOHOL, PHILIPPINES

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Abstract. Seagrass ecosystem is an important component of the coastal and marine biodiversity, yet seagrasses remain in decline in the Philippines. This study carried out spatial assessment on seagrass ecosystem in Maribojoc Bay. The spatial dataset consists of geographic, ecological and social data. Particularly, this study determined the spatial associations across environmental variables with seagrass biotic variables. Seven species of seagrass were identified and the occurrence ranged from *Thalassia–Enhalus* bed to a maximum of seven species in mixed communities. Maribojoc Bay had a "fair" seagrass condition. The findings of the study provide spatial data demonstrating that seagrass ecosystem in Maribojoc Bay was influenced by several environmental factors and land-use practices. Land-use related to human development had the most important impact on seagrass biological variables in the present study. Seagrass beds adjacent to human development showed lower seagrass density, species richness, percent cover and *Th* shoot density. Hence, the nature of coastal land is an important determinant of seagrass health and condition. The findings of the study suggest that mitigating human activities on land adjacent to seagrass communities is more important for maintaining seagrass biodiversity. It is therefore important to consider both marine and land-based strategies for mitigating declines in seagrasses and degradation.
Keywords: *seagrass, land-use practices, coastal protection, spatial assessment*

Introduction

Seagrasses form important underwater marine ecosystems that support coastal communities around the world (McKenzie et al., 2010), yet they remain in decline and largely marginalized on conservation agendas (Micheli et al., 2013; Coles et al., 2011). Seagrasses are declining at a rate that may be as high as 7 percent of their global area per year (Waycott et al., 2009). This is mainly due to multiple environmental stressors, often attributable to human activities (Orth et al., 2006). According to various studies, the global decline of seagrass ecosystems threatens to exacerbate climate change (Lavery et al., 2013; Fourqurean et al., 2012; Duarte et al., 2010; Kennedy et al., 2010), undermining the supply of a range of other ecosystem services (Cullen-Unsworth and Unsworth, 2013; Short et al., 2011; Bujang et al., 2006) and consequently detrimentally affect subsistence livelihoods (Nordlund et al., 2011; Unsworth et al., 2010).

In the Philippines, the rapid disappearance of seagrass is due to the increasing and multiple demands of the people upon the country's marine environment and unsustainable human activities. At present, environmental problems and their impacts to seagrass ecosystems have become more complex. In addition, these aquatic plants are unfamiliar or unknown to most Filipino. This contributes to the rapid depletion of the seagrass meadows in the country (Fortes, 2013). In Bohol, seagrass ecosystems are gradually lost

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by uncontrolled development at the coastal areas (Green et al., 2002). Maribojoc Bay, the largest bay in the province is one particular area that is significantly affected by intense human pressure. The bay serves a major seaport for passenger and cargo ships. Lying on its coast are the towns of Maribojoc, Cortes, Tagbilaran City, Dauis and Panglao. Demographic data showed that Tagbilaran City remains the most populated area in Bohol, while the two municipalities in Panglao Island, Dauis and Panglao topped the population growth rate based on 2015 census of Philippine Statistics Authority (PSA). As such, seagrass habitats could be severely affected by human activities, not only to high population densities but also to development pressures in the coastal area. Seagrass beds could be destroyed in the process of providing living space for buildings, residential development, tourist resorts, and recreation areas. Land reclamation for coastal development and excessive sedimentation from river sand extraction are threatening the seagrass ecosystem. If these problems will continue unabated, it will result to seagrass loss and the ecological integrity of Maribojoc bay may be threatened causing the natural productivity and ecosystem values to be compromised and degraded. Consequently, there is growing interest in integrating terrestrial and marine conservation in the coastal zone (Alvarez-Romero et al., 2011; Beger et al., 2010; Tallis et al., 2008; Richmond et al., 2007; Cicin-Sain and Belfiore, 2005; Stoms et al., 2005).

This study was conducted to determine the potential impacts on seagrass ecosystem in Maribojoc Bay, Bohol. Specifically, this study determined the spatial associations between seagrass biological variables and environmental variables as well as land-use practices. It is necessary to consider terrestrial and coastal areas as a single spatial unit to understand the complex interactions between human and natural systems. Likewise, to integrate the spatial data to assess conservation opportunities and priorities for the seagrass ecosystem in Maribojoc Bay.

Materials and methods

Study area and sampling

Maribojoc Bay is situated in the southwestern part of the island province of Bohol, Philippines covering the coastal areas of the four municipalities of Maribojoc, Cortes, Dauis, Panglao, and the city of Tagbilaran (*Fig. 1*). It has a total of 73.4 km of coastline and covers an area of 145 km^2. Four sampling stations were established in the municipalities of Maribojoc, Tagbilaran, Dauis, and Panglao. At each station, two sites were surveyed, for a total of eight survey sites, of which four are classified as Marine Protected Areas (MPAs) and four are non-MPAs. The study was conducted in eight sites from July to December 2020.

This study followed a standardized field sampling design consisting of three fixed, parallel, 50 m transects. At each sampling site, three transect lines were laid perpendicular to the shoreline, each separated from the other by a distance of 100 m. For each transect line, a quadrat measuring 50 cm × 50 cm was laid at 5-m intervals along each transect. A total of 11 quadrats were sampled. Biotic variables such as species composition, abundance, percent cover and distribution were measured from a 50-cm^2 quadrat. Algal associations and epiphytes cover were also examined at each quadrat. Canopy height and shoot density of the dominant species was counted from a 25-cm^2 quadrat (Short et al., 2006; McKenzie et al., 2003). Identification of seagrass species was based on the identification keys by McKenzie et al. (2003) and the classification system used by Fortes (2013).

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At the 0 m, 25 m, and 50 m points along each line, the following physico-chemical parameters were measured: salinity (refractometer), temperature (mercurial thermometer), DO (DO meter), pH (pH meter), depth (meter tape) and underwater horizontal visibility (secchi disk). Subtrate type was determined through texture and by noting the grain size in order of dominance (e.g. sand, fine sand, mud, rocks, etc.). GPS coordinates of the starting and the end point of transects were recorded. Sampling was done during intertidal, and subtidal using snorkeling or scuba equipment. GPS coordinates of the starting and the end point of transects were recorded. Positions, areas of seagrass, and extent for each study site were also recorded by GPS. The date, time, tidal information, and other relevant observations found were also entered in the data sheet (Short et al., 2006; McKenzie et al., 2003).

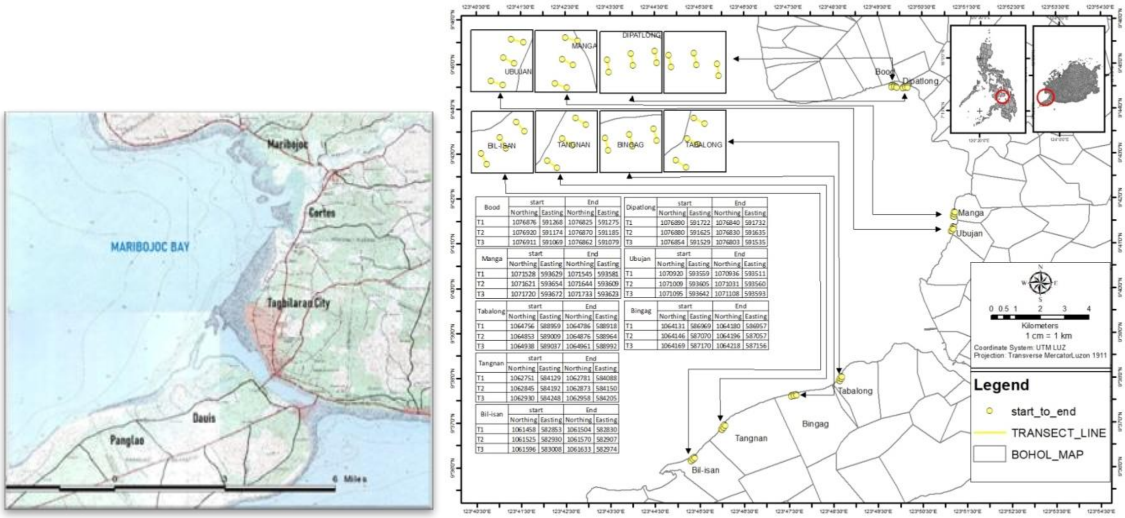

***Figure 1.** Location map of sampling stations and transect lines in the eight study sites of Maribojoc Bay, Bohol*

Calculation of relative abundance and seagrass coverage

Relative abundance was calculated to determine the species abundance and its distribution. Species abundance was determined by calculating the total number of individual species (n) divided the total number of species population (N) and multiply by one hundred (100). The relative abundance maybe given in percentage (%).

$$\text{Relative Abundance (\%)} = (n/N) \times 100$$

where n = individual species count; N = total species count.

Estimation of the percent cover for each seagrass species found in each quadrat was done through ocular estimates based on the seagrass percentage cover photo guide (McKenzie et al., 2007). Calculations for the cover (C) of each species in each 50 cm × 50 cm quadrat are as follows:

$$C = \frac{\Sigma\,(M_i \times f_i)}{\Sigma f}$$

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The seagrass coverage for each transect was determined by dividing the sum of the average cover for each quadrat by the number of quadrats utilized. The corresponding percent cover per sampling site was determined by getting the total percent cover of transects divided by the number of transects used for each sampling site. The percentage of seagrass cover of each sampling site was then categorized using the categories used by Jackson and Nemeth (2007), where poor = 0-25%, fair = 26-50%, good = 51-75% and excellent = 76-100%.

Spatial data assessment

The spatial dataset consists of geographic, ecological and social data. Geographic data include elevation, topography, the municipal boundaries, and coastline data, and these are used as basic information for spatial assessment. Ecological data consist of seagrass biotic data and seagrass habitat information. Seagrass biotic and abiotic data were generated from the survey conducted. Additional data was obtained on *Thalassia hemprichii* (e.g. canopy height and shoot density) as a canopy forming, climax species in the seagrass assemblage of Maribojoc Bay. Spatial distribution of seagrass area in Maribojoc Bay was mapped using remote sensing and GIS. Satellite remote sensing imagery through Landsat was used in this study. It is a multispectral satellite developed by the United States Geological Survey (USGS). In this study, spectral radiance for landsat images was given by landsat 8, the Operational Land Imager (OLI)/ and the Thermal Infrared Sensor (TIRS) circa 2020. Considered in the download of the images are the absence of clouds and tidal conditions. Data processing will be through existing Geo Cover and Landsat archive to produce near-global, cloud-free mosaic (Long and Giri, 2011). Validation and training points collected in the field mapping are processed into shapefiles and are used in the supervised classification of the image. The entire image pre-processing, classification and accuracy assessment was completed using the tools in Arc Map software. The total seagrass area mapped in Maribojoc Bay is 1,129.55 ha that is represented by green color (*Fig. 2*).

Social data involved land use and coastal population. Land use by definition describes the use of land by people for different activities. Some information plotted in the land use map (*Fig. 3*) was provided by the concerned municipal local government unit (MLGU), which they extracted from their comprehensive land use plan (CLUP) for 2020-2025. In this study, land use was classified into human development (e.g. built-up, tourism facilities, infrastructures, residential, fish landing, ports and roads), coastal vegetation (e.g. mangroves, scattered trees and grasses/shrubs) and bare land (e.g. exposed rocks and soil). Visual assessment was performed on land uses covering the coastal strip area about 50 m. The area of each MPA surveyed was determined and then classified as closed or open in relation to its accessibility. Coastal population was based on 2015 census of Philippine Statistics Authority (PSA).

Data analysis

One-way analysis of variance (ANOVA) was used to test for significant differences among sampling stations at an alpha ($\alpha = 0.05$) level of confidence. Potential differences between MPAs and non-MPAs were also determined. A post-hoc test was used in defining the subsets of variance that contribute to differences among sampling stations and between sampling sites. The data was analyzed using SPSS.

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Figure 2. Map showing the seagrass area in Maribojoc Bay, Bohol. (Photocredit: PPDO-Bohol & DENR-Bohol)

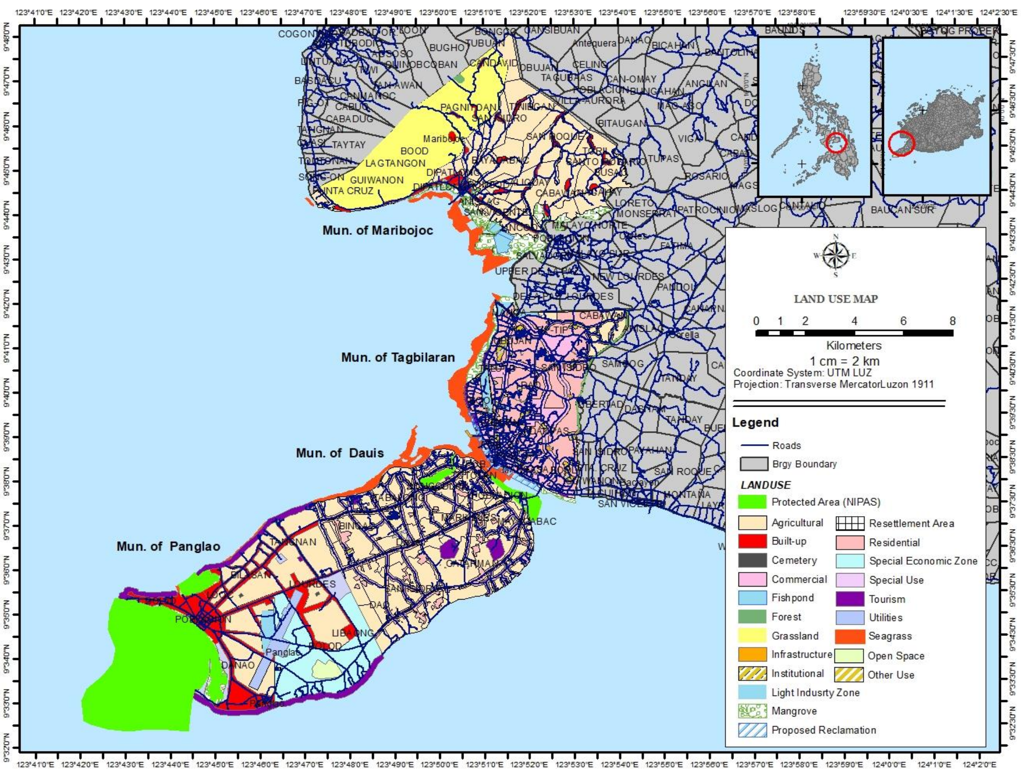

Figure 3. Land use map in Maribojoc Bay, Bohol. (Photocredit: PPDO-Bohol & DENR-Bohol)

Canonical correspondence analysis (CCA) was used to examine potential threats and the relationships between seagrass biological and environmental/land-use variables. Non-metric multidimensional scaling (NMDS) analysis depicting the community structure of the seagrasses in Maribojoc Bay was shown along two-dimension axes and set with Bray–Curtis dissimilarity units.

Results

Seagrass composition, abundance and percent cover

Seven species of seagrass were found in surveyed sites, namely *Cymodocea rotundata*, *Enhalus acoroides*, *Halodule pinifolia*, *Halodule uninervis*, *Halophila ovalis*, *Syringodium isoetifolium* and *Thalassia hemprichii (Table 1)*. The occurrence of seagrass species ranged from *Thalassia–Enhalus* bed to a maximum of seven species in mixed communities. In terms of relative abundance (*Fig. 4*), *Thalassia hemprichii* provide consistent coverage and obtained the highest percentage (52.79%). The remaining seagrass relative abundance were *Enhalus acoroides* (18.85%), *Cymodocea rotundata* (9.55%), *Halodule uninervis* (7.48%), *Halophila ovalis* (7.20%), *Syringodium isoetifolium* (3.96%) and *Halodule pinifolia* (0.18%) respectively. Species richness showed the following order Dauis > Panglao = Maribojoc > Tagbilaran. Seagrass total abundance and percentage cover was higher in Maribojoc, followed by Panglao, Dauis and Tagbilaran City respectively.

Table 1. *Species composition and the relative frequency of seagrass species in the surveyed sites and stations in Maribojoc Bay, Bohol*

Species	Maribojoc		Tagbilaran		Dauis		Panglao	
	Bood MPA	**Dipatlong**	**Manga MPA**	**Ubujan**	**Bingag MPA**	**Tabalong**	**Bil-isan MPA**	**Tangnan**
Cymodocea rotundata	1 +	1 +	2 +	-	2 +	1 +	2 +	1 +
Enhalus acoroides	3 +	3 +	2 +	6 +	1 +	2 +	1 +	-
Halodule pinifolia	-	1 +	-	-	1 +	1 +	-	-
Halodule uninervis	1 +	2 +	-	-	1 +	1 +	3 +	1 +
Halophila ovalis	1 +	1 +	2 +	-	1 +	1 +	1 +	2 +
Syringodium isoetifolium	-	-	-	-	1 +	2 +	2 +	2 +
Thalassia hemprichii	6 +	5 +	6 +	4 +	6 +	6 +	5 +	6 +
Total species	**5**	**6**	**4**	**2**	**7**	**7**	**6**	**5**

-: absent in all quadrats, 1+: present in 1-9% of all the quadrats, 2+: present in 10-19% of all the quadrats, 3+: present in 20-29% of all the quadrats, 4+: present in 30-39% of all the quadrats, 5+: present in 40-49% of all the quadrats, 6+: present in more than 50% of all the quadrats

Generally, sites with “good” seagrass cover such as Brgy. Dipatlong, Brgy. Tabalong and Brgy. Bil-isan have lower percentage of abiotic components (*Fig. 5*). While, Tagbilaran with poor seagrass cover (24.61%) had higher algae cover (13.77%) and abiotic components (62.23%). However, if treated by stations, seagrass percentage cover of Maribojoc (45.53%), Panglao (43.93%) and Dauis (40.53%) with “fair” seagrass condition have higher percentage of abiotic components. Overall, Maribojoc Bay had “fair” seagrass condition (38.65%), with percentage algae cover of 7.44%, corals (8.81%) and abiotic components of 45.11%.

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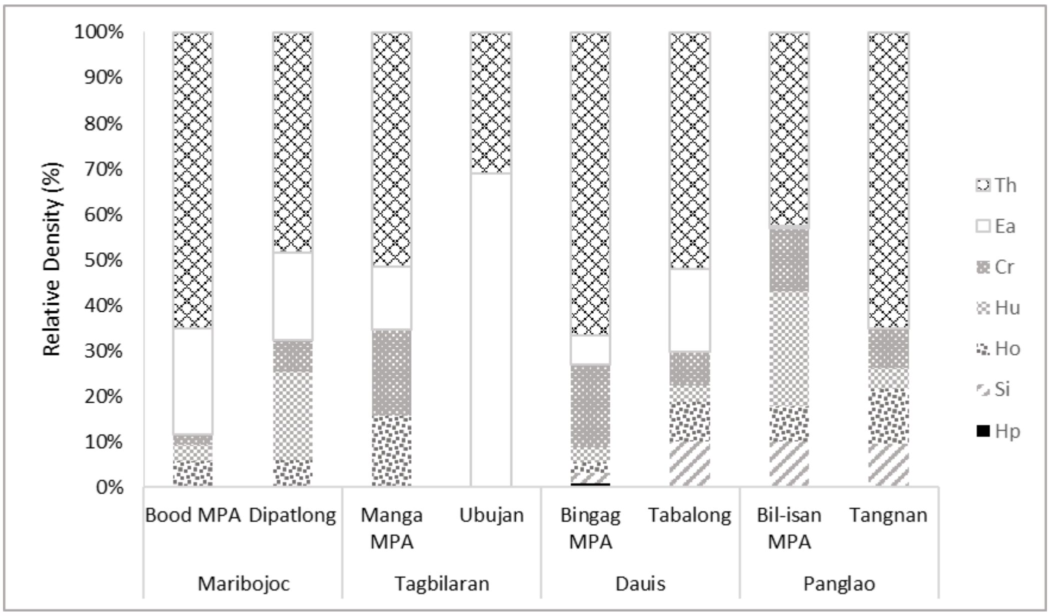

Figure 4. *Relative densities (%) of the 7 seagrass species observed in the surveyed sites and stations in Maribojoc Bay, Bohol*

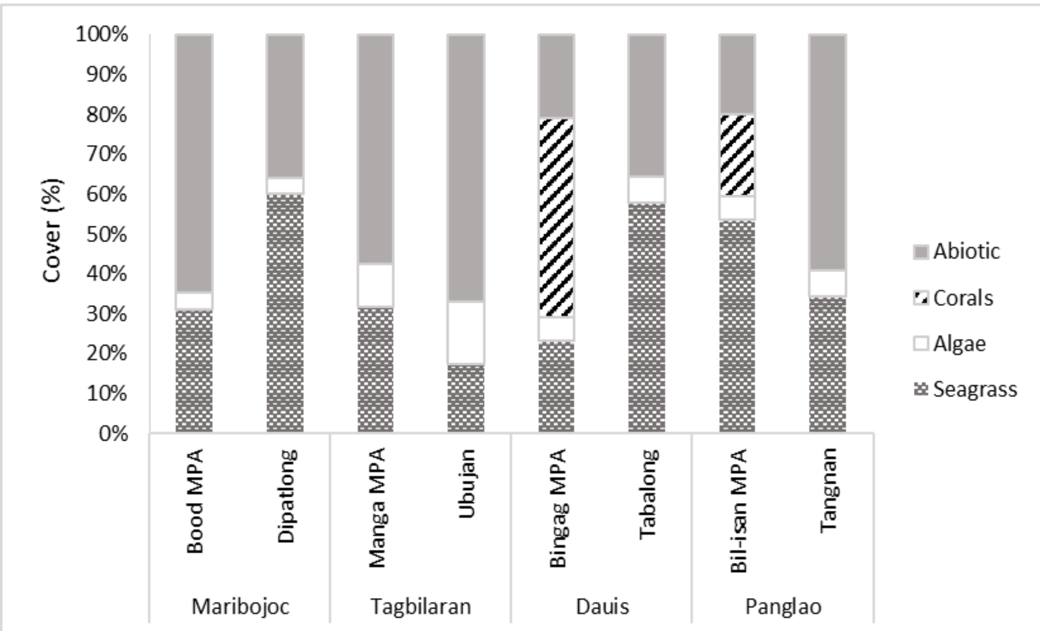

Figure 5. *Coverage (%) of habitat structural components of seagrass beds in the surveyed sites and stations in Maribojoc Bay, Bohol*

Canopy height and shoot density

The canopy height of the most dominant and widely distributed seagrass species, *Thalassia hemprichii* had a mean average of 13.54 cm. The highest canopy height was recorded in Brgy. Bood, Maribojoc (17.78 cm), while Brgy. Tangnan, Panglao (10.62 cm) had the lowest among surveyed sites. Among sampling stations, the highest canopy height was recorded in Maribojoc (15.78 cm), followed by Panglao (13.53 cm),

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Tagbilaran City (13.17 cm) and Dauis (11.70 cm), respectively (*Fig. 6*). ANOVA analysis (*Table 2*) showed no significant difference (p > 0.05) on *T. hemprichii* canopy height among sampling stations (F (3, 20) = 1.486, p = 0.249).

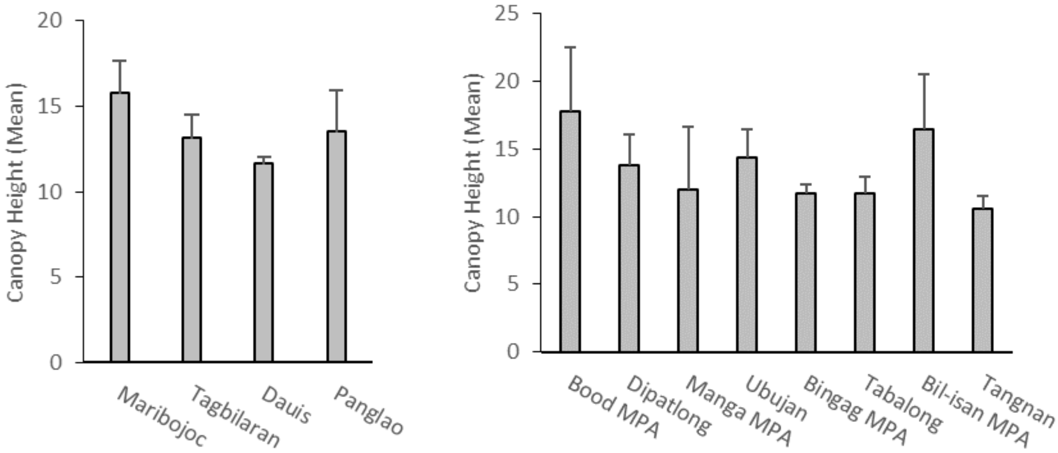

Figure 6. *Comparison on T. hemprichii canopy height (per 0.50 m^2) in four sampling stations and between MPAs and non-MPAs (error bars are standard deviation)*

In terms of shoot density, *Thalassia hemprichii* had a mean average of 33.75. The highest shoot density was recorded in Brgy. Bil-isan, Panglao (68.99), while Brgy. Manga, Tagbilaran (15.41) had the lowest among surveyed sites. Among stations, the highest shoot density was recorded in Panglao (108.56), followed by Dauis (70.49), Maribojoc (42.89) and Tagbilaran (24.04), respectively (*Fig. 7*). One-way ANOVA analysis (*Table 2*) showed significant difference (p < 0.05) on shoot density among sampling stations (F (3, 20) = 5.214, p = 0.008). A Tukey post hoc test revealed significant difference on shoot density between Maribojoc and Panglao (p = 0.010) and Tagbilaran and Panglao (p = 0.018). Meanwhile, there was no significant difference between Dauis and the three stations in terms of shoot densities.

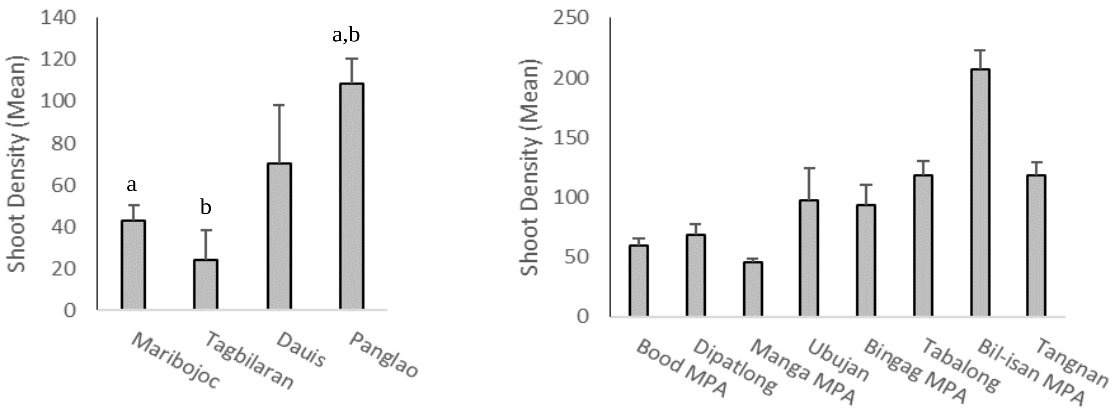

Figure 7. *Comparison on T. hemprichii shoot density (per 0.25 m^2) among sampling stations and between MPAs and n-MPAs (error bars are standard deviation). Post hoc test showing similarity based on shoot density and values with the same superscript showed significant difference*

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Table 2. *Analysis of variance (ANOVA) to test mean difference on T. hemprichii canopy height and shoot density across sampling stations (P < 0.05)*

		Sum of squares	df	Mean square	F	Sig.
Canopy height	Between groups	51.233	3	17.078	1.486	0.249
	Within groups	229.867	20	11.493		
	Total	281.100	23			
Shoot density	Between groups	4017.307	3	1339.102	5.214	0.008
	Within groups	5136.085	20	256.804		
	Total	9153.392	23			

Physico-chemical parameters

The different physico-chemical parameters of the four sampling stations were measured during sampling period (*Table 3*). The temperature mean was 32.40°C across the four sampling stations (SD = 1.1, N = 72), of which Tagbilaran had the highest mean temperature (35.10°C), followed by Maribojoc (33.15°C), Panglao (30.75°C) and Dauis (30.60°C), respectively. The pH mean was 7.65 (SD = 1.3, N = 72). The pH mean was higher in Dauis (8.03), followed by Panglao (8.00), Maribojoc (7.32) and Tagbilaran City (7.25) respectively. Salinity had the mean value of 33.51 (SD = 3.3, N = 72) across the four sampling stations. The highest salinity was recorded in Dauis (36.05), followed by Panglao (34.65), Tagbilaran City (32.20) and Maribojoc (31.15), respectively. Dissolved oxygen (DO) mean value was 8.54 (SD = 1.2, N = 72), where mean was slightly higher in Dauis (10.10), followed by Panglao (9.55), Maribojoc (8.50) and Tagbilaran (6.00), respectively. The mean horizontal visibility was 4.55 m. Higher visibility was recorded in Panglao (6.35 m), followed by Dauis (5.40 m), Maribojoc (4.20 m) and Tagbilaran (2.25 m). Substrate types were categorized as sandy-muddy in Maribojoc and Tagbilaran, while, sandy-rocky in Dauis and Panglao.

Table 3. *Recorded mean abiotic factors of seagrass beds in Maribojoc Bay, Bohol*

Parameters	Maribojoc	Tagbilaran	Dauis	Panglao
Temperature (°C)	33.15	35.10	30.60	30.75
pH	7.32	7.25	8.03	8.00
Salinity (ppt)	31.15	32.20	36.05	34.65
DO (ppm)	8.50	6.00	10.10	9.55
Horizontal visibility (m)	4.20	2.25	5.40	6.35
Substrate type	Sandy-muddy	Sandy-muddy	Sandy-rocky	Sandy-rocky

Relationship between biological and environmental variables

The ordination diagram (*Fig. 8*) describes the relationship between seagrass biological and environmental/land use variables (*Table 4*), on the two axes of the Canonical Correspondence Analysis (CCA). The ordination analysis reveals that there is high correlation (r value from 0.1134-0.4265), and the cumulative percentage variance indicates that 79.63% of seagrass biological variables by station is explained by environmental variables. The results of the Global permutation Test indicate that the relation between seagrass biological variables and environmental variables is

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highly significant. The test of significance based on the sum of all canonical eigenvalue is 0.6779 and the resulting p-value is 0.008 indicating that the measured environmental variables significantly explain the seagrass biological variables at 0.05 level.

Table 4. *Summary of seagrass biological variables and environmental variables incorporated in the present study*

Seagrass Variables	Maribojoc		Tagbilaran		Dauis		Panglao	
	Bood MPA	**Dipatlong**	**Manga MPA**	**Ubujan**	**Bingag MPA**	**Tabalong**	**Bil-isan MPA**	**Tangnan**
Biological variables Species density (m^2)								
Cymodocea rotundata	2.34	6.82	19.08	0.00	18.22	7.41	14.04	8.47
Enhalus acoroides	23.41	19.39	13.93	69.00	6.46	18.12	0.51	0.00
Halodule pinifolia	0.00	0.25	0.00	0.00	0.90	0.26	0.00	0.00
Halodule uninervis	3.41	19.39	0.00	0.00	3.23	3.73	25.20	4.85
Halophila ovalis	5.76	5.76	15.55	0.00	2.33	8.61	7.64	11.92
Syringodium isoetifolium	0.00	0.00	0.00	0.00	2.20	9.82	10.14	9.53
Thalassia hemprichii	65.07	48.38	51.43	31.00	66.67	52.05	42.47	65.23
Species richness	5	6	4	2	7	7	6	5
Total seagrass cover (m^2)	31.06	60.00	31.76	17.45	23.36	57.70	53.52	34.33
Total seagrass density	341.67	660.00	349.33	192.00	258.00	634.67	588.67	377.67
Th canopy height (m^2)	17.78	13.77	12.00	14.33	11.68	11.71	16.43	10.62
Th shoot density (m^2)	19.87	23.02	15.41	32.67	31.10	39.39	68.99	39.58
Environmental variables								
Temperature (°C)	33.3	33.0	34.5	35.7	30.2	31.0	30.3	31.2
pH	7.28	7.35	7.26	7.24	8.04	8.01	8.03	7.97
Salinity (ppt)	31.0	31.3	32.3	32.1	36.4	35.7	34.3	35.0
DO (ppm)	8.4	8.6	6.7	5.3	10.3	9.9	10.4	8.7
Horizontal visibility (m)	4.1	4.3	2.4	2.1	5.5	5.3	6.5	6.2
Substrate: sandy-muddy	1	1	1	1	0	0	0	0
Substrate: sandy-rocky	0	0	0	0	1	1	1	1
% Algae cover (m^2)	4.28	4.08	10.7	15.6	5.58	6.75	6.07	6.39
% Epiphytes cover (m^2)	9.50	6.20	2.00	2.00	5.00	3.27	21.25	6.25
Land-use coastal vegetation	3	4	2	1	2	1	3	1
Land-use human devt.	0	0	4	4	0	2	0	2
Land-use bare ground	0	0	1	2	2	2	2	2
MPA	1	0	1	0	1	0	1	0
MPA open (km^2)	12.26	0	15.45	0	0	0	0	0
MPA closed (km^2)	0	0	0	0	6.70	0	7.76	0
Coastal population	426	1495	7224	5574	4436	5375	3649	3645

*Land-use variables were assessed using the following rating: 0 absent, 1 scarce, 2 regular, 3 high, 4 very high. Substrate type and MPA were scored: 0 absent, 1 present

The scatter plot visualizes the correlation between seagrass biological variables and environmental variables (Ter Braak and Smilauer, 2002). The lines pointing in the same direction indicate that the corresponding explanatory variables are correlated with each other. In the present study, the diagram showed *Th* canopy height and pH were closely correlated with each other in station Maribojoc. Whereas, environmental variables such as algae cover, temperature, sandy-muddy substrate and salinity were found correlated with each other in station Tagbilaran, which were also closely correlated to seagrass species *E. acoroides*. Meanwhile, land-land use related variables such as human

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development, coastal population and open MPA were also correlated with each other in station Tagbilaran. Furthermore, the diagram showed that seagrass biological variables such as *Th* shoot density, seagrass total density, percent cover, species richness and four seagrass species *Hu*, *Si*, *Hp* and *Cr* were correlated with each other in station Panglao, which were also correlated with environmental variables such epiphyte cover, DO, horizontal visibility and sandy-rocky substrate. Land-use related variables such as vegetation and closed MPA were also correlated with seagrass biological and environmental variables in station Panglao. Meanwhile, seagrass species *Ho*, *Th* and presence of MPA are closely correlated with each other in station Dauis. However, long lines are more important than short ones, the longer the arrow relative to the other arrows, the greater the contribution of the variable in the formation of the axes. Species richness was the longest line while baren ground was found to be the shortest line among variables incorporated in the analysis.

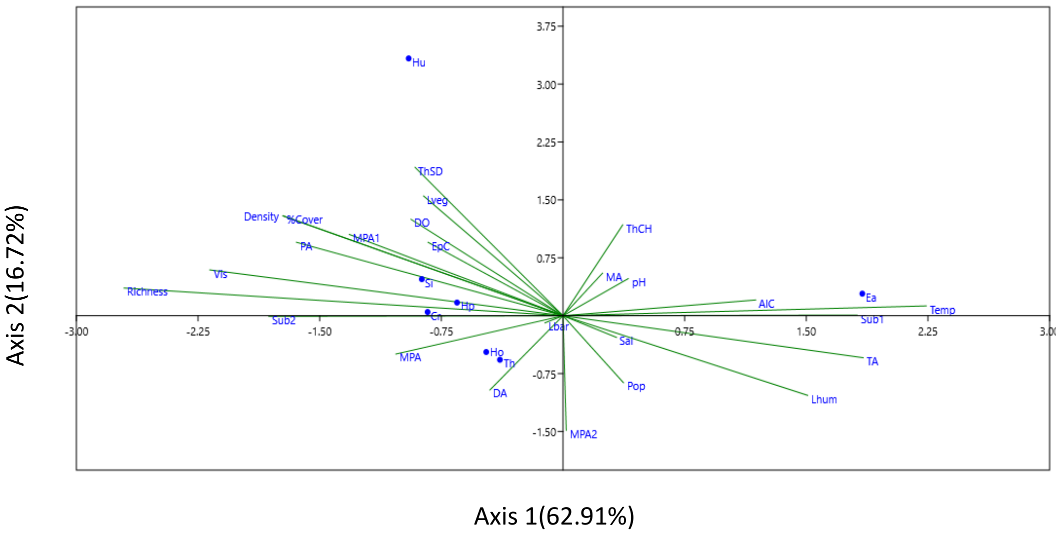

Figure 8. *Ordination diagram of seagrass biological variables and environmental/land-use variables on axes 1 and 2 of the CCA. Seagrass biological variables represented by dots are seagrass species density: Cr-Cymodocea rotundata, Ea-Enhalus acoroides, Hp-Halodule pinifolia, Hu-Halodule uninervis, Ho-Halophila ovalis, Si-Syringodium isoetifolium and Th-Thalassia hemprichii. Seagrass biological variables represented by lines are Richness-species richness, %Cover-total seagrass % cover, Density-total seagrass density, ThCH-Th canopy height, ThSD-Th shoot density. Environmental variables represented by lines include biotic, abiotic and land-use variables. Biotic variables: AlC-algae cover and EpC-epiphytes cover. Abiotic variables: Tem-Temperature, Sal-salinity and substrate type: sub1-sandymuddy and sub2-sandyrocky. Land-use variables: Lhum-human development, Lveg-vegetation, Lbar-bare ground. MPA-marine protection: MPA1-closed MPA, MPA2-open MPA. Pop-coastal population. Stations are indicated by MA-Maribojoc, TA-Tagbilaran, DA-Dauis and PA-Panglao*

Lines pointing in opposite directions are negatively correlated and also the lines with an angle of 90 degrees indicate that the two variables are uncorrelated. The diagram showed that variables such as *Th* canopy height and pH in station Maribojoc were negatively correlated with the seagrass species *Ho*, *Th* and presence of MPA in station Dauis. Moreover, various seagrass biological and environmental variables correlated in

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station Panglao were uncorrelated with salinity, coastal population and human development in station Tagbilaran.

The same integration holds for the species. The seagrass species close to a particular variable is highly correlated. The clear clustering of species in the diagram, suggests that there are strong associations among seagrass species *Si*, *Hp* and *Cr*. However, the species plot close to the center of the ordination diagram also indicates no strong association with any of the environmental variables incorporated in the analysis. Among the seven seagrass species, *E. acoroides* and *H. uninervis* showed strong association with the environmental variables incorporated in the analysis.

The first axis of the CCA (*Table 5*) indicates a strong influence of environmental variables on seagrass biological variables and explained about 62.91% of the overall variance (r = 4265, p = 0.03). The canonical coefficients in the present study revealed that seagrass *E. acoroides* is highly and positively correlated with the first axis (r = 1.8451). This implies that species *E. acoroides* is the most important variable among canonical variables in the first axis. Environmental variables such as temperature (r = 0.6398), station Tagbilaran (r = 0.5287), sandy-muddy substrate (r = 0.5182), human development (r = 0.4310), algae cover (r = 0.3393) are also positively and highly correlated with the first ordination axis. The CCA in axis 2 explain only 16.72% of the overall variance (r = 0.1134, p = 0.09). Seagrass *H. uninervis* is highly and positively correlated with the second axis (r = 3.3335). This implies that species *H. uninervis* is the most important variable among canonical variables in the second axis. Then followed by species *Si* (r = 0.4740). Biological variables such as *Th* shoot density (r = 0.5493), percentage cover (r = 0.3700), total seagrass density (r = 0.3697), *Th*CH and environmental variables such as DO (r = 0.3570) and land use coastal vegetation are also positively and highly correlated with the second ordination axis.

Non-metric multidimensional scaling (NMDS) of seagrass community structures were determined by the two axes (*Fig. 9*). The 2-D stress result of 0.03 (<0.05) indicates an excellent presentation of the data. The NMDS analysis clearly showed seagrass biological variability among sites were principally related to local environment conditions. The proximity of the sites to each other indicates how similar they are to each other. The first axis (nMDS1) was strongly associated to community structures in Tagbilaran sites. However, the first scaled dimension showed similarity between Tagbilaran and Dauis sites, while the second axis (nMDS2) was more associated to community structures in Panglao sites. However, the first scaled dimension showed similarity between Dauis and Panglao sites. On the other hand, Maribojoc sites were separated from the three stations along the first and second scaled dimension respectively.

Discussion

A total of seven species of seagrass were observed in Maribojoc Bay, Bohol. The species represented by *Cymodocea rotundata*, *Enhalus acoroides*, *Halodule pinifolia*, *Halodule uninervis*, *Halophila ovalis*, *Syringodium isoetifolium* and *Thalassia hemprichii*. The most abundant and dominant seagrass species was *T. hemprichii*, which implies highly tolerant on various environmental conditions. This species, *T. hemprichii* was considered a climax species in the Indo-pacific region and when present in mixed seagrass meadows it usually dominates over the other seagrass species (Lacap et al., 2002; Short et al., 2010). In the Philippines, *T. hemprichii* has the widest range of

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temperature tolerance (Fortes, 2013). On the other hand, the species that has been collected with least cover was *H. pinifolia*. In comparison to other seagrass species, *H. pinifolia* is less common, which suggests that it is less tolerant of the prevailing hydrographic parameters (Mascariñas and Otadoy, 2020). Moreover, the difference in the number of species identified in Maribojoc Bay could be one of the factors for the deterioration of seagrass ecosystem. Similarly, anthropogenic disturbances on various sampling sites were likely to influence the percent frequency and distribution of seagrass species.

Table 5. *Summary of canonical analysis (CCA) performed on seagrass biological and environmental/land-use variables. Canonical coefficients showed the direction of the relationship between biological and environmental/land-use variables. Coefficients > 0.3 are interpreted as meaningful. Canonical coefficients are the first two axes of the CCA. Canonical coefficients highlighted in bold best explained the CCA model*

Seagrass variables	**CCA = 0.6779** **Percentage = 79.63**	**p = 0.008**
	Canonical coefficients	
	Axis 1 (62.91%)	**Axis 2 (16.72%)**
Biological variables		
Seagrass species density (m^2)		
Cymodocea rotundata	-0.8348	-0.0481
Enhalus acoroides	**1.8451**	0.2864
Halodule pinifolia	-0.6534	0.1707
Halodule uninervis	-0.9514	**3.3335**
Halophila ovalis	-0.4735	-0.4697
Syringodium isoetifolium	-0.8704	**0.4740**
Thalassia hemprichii	-0.3890	-0.5702
Species richness	-0.7733	0.1026
Total seagrass % cover (m^2)	-0.4937	**0.3697**
Total seagrass density (m^2)	-0.4931	**0.3700**
Th canopy height	0.1052	**0.3364**
Th shoot density	-0.2606	**0.5493**
Environmental variables		
Temperature (°C)	0.**6398**	0.0363
pH	0.1149	0.1375
Salinity (ppt)	0.0941	-0.0802
DO (ppm)	-0.2678	**0.3570**
Horizontal visibility (m)	-0.6222	0.1697
Substrate1: sandy-muddy	**0.5182**	0.0023
Substrate2: sandy-rocky	-0.5182	-0.0023
% Algae cover (m^2)	**0.3393**	0.0584
% Epiphytes cover (m^2)	-0.2378	0.2719
Land-use coastal vegetation	-0.2456	**0.4432**
Land-use coastal human development	**0.4310**	-0.2947
Land-use coastal bare ground	0.0318	-0.0262
Marine protected area (MPA)	-0.2945	-0.1417
MPA enclosed	-0.3765	**0.3009**
MPA open	0.0057	-0.4241
Coastal population	0.1065	-0.2480
Station Maribojoc	0.0697	0.1579
Station Tagbilaran	**0.5287**	-0.1552
Station Dauis	-0.1289	-0.2747
Station Panglao	-0.4695	0.2720

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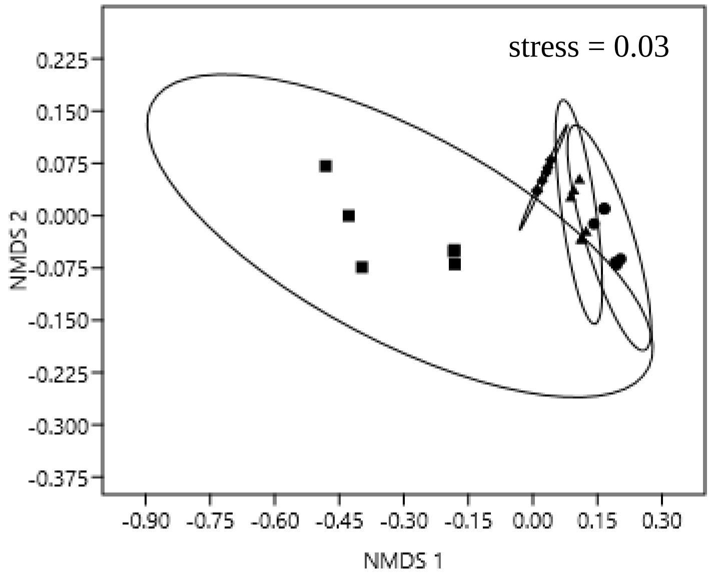

Figure 9. *Non-metric multidimensional scaling (NMDS) analysis of the seagrass community structures in Maribojoc Bay, Bohol*

Seagrass condition were poor-fair in four stations, with overall fair condition (38.65%) or sparse coverage. Only Tagbilaran had the poor seagrass condition. Thus, the state of seagrass ecosystem in Maribojoc Bay is alarming and believed to continuously decrease due to rampant disturbances and degradations (Mascariñas and Otadoy, 2020). Studies found that seagrass species population declines are due both directly or indirectly to anthropogenic impacts (Waycott et al., 2009; Short et al., 2011). Due to its proximity to shore, seagrasses are vulnerable to changes both land and sea use (Orth et al., 2006; Cullen-Unsworth et al., 2014). Fortes (2013) stated that human causes of seagrass loss and degradation can result from direct marine-based activities (e.g. dredging, coastal and marine development, fishing disturbance, mooring, anchoring, and aquaculture) as well as indirect land-based activities (e.g. nutrient and sediment loading from terrestrial urbanization, agriculture development, deforestation). In the Philippines, about half of the seagrass beds have either been lost or severely degraded over the past 50 years and the rate of degradation is increasing (DA-BFAR, 2004).

The influence of environmental variables on seagrass biological variables were examined and found that 79.63% variance of seagrass biological variables by station is explained by environmental variables. The most important seagrass species that showed strong association with the environmental variables is *Enhalus acoroides*. This species known to be robust to disturbances abound the shores of Tagbilaran. Besides, relative abundance of *E. acoroides* was highest in Tagbilaran. Furthermore, *E. acoroides* was strongly associated with high temperatures, sandy-muddy substrate and higher algae cover. The large, slow-growing *E. acoroides* is a climax species that has been demonstrated to be resilient to light reduction and enhanced sedimentation (Williams et al., 2017; Erftemeijer et al., 2006). Abundance of *E. acoroides* can be due to the effect of muddy-sandy substrate. Compared to other seagrass species, *E. acoroides* was observed to be the most tolerant to siltation (Terrados et al., 1998;

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Khogkhao et al., 2017) and can thrive in diminished physical conditions (Quiros et al., 2017). It was also noted, the thick mats of algae in Tagbilaran. Algal bloom could be an indicator of the presence of eutrophication caused by the increased of nutrients in the water such as nitrates and phosphates but can dramatically increase because of anthropogenic factors such as siltation and pollution. According to Fortes (2013), anoxia in water occurs due to rise of temperatures and low tidal conditions resulting to green algae proliferation.

In this study, dissolved oxygen (DO) was the only in situ environmental variable that had a strong influenced with seagrass biological variables. This implies that higher DO showed the greatest effect on the occurrence and distribution of seagrass species *H. uninervis*. This species was encountered in three stations, except Tagbilaran. Likewise, *S. isoetifolium* was also strongly associated with higher DO. This species was only observed in stations Dauis and Panglao, of which water had higher horizontal visibility and the substrate type is generally a combination of both sand and rock. Moreover, *S. isoetifolium* can be found in clear waters and prefers sandy substrates (Green and Short, 2003). Other seagrass biological variables such as higher *Th* shoot density, percentage cover, seagrass density and *Th* canopy height were also strongly associated with higher DO. Notably, dissolved oxygen (DO) is one of the most important indicators for growth and survival of seagrasses. Seagrasses are obligate aerobes, which require a continuous supply of oxygen to sustain aerobic metabolism of above-and below-ground tissues. On particular, the meristematic tissues located in the transition between water column and sediment, are especially vulnerable to low oxygen supply and exposure to anaerobic metabolites due to their high metabolic activity and the continuous oxygen supply required for mitotic growth. In addition to the importance of oxygen inside seagrass tissues, maintenance of oxic conditions around roots may provide efficient protection against invasion of reduced toxic compounds and metal ions from the surrounding sediments (Greve et al., 2003: Borum et al., 2006).

Land-use related to human development had the most important impact on seagrass biological variables in the present study. Human development defined as the presence of built-up, houses, commercial development and roads were the most important land use that determined seagrass condition. In Tagbilaran, results of the seagrass survey revealed lower species density, species richness, total density, percentage cover and *Th* shoot density. These patterns may be indicative of the effect of human presence on seagrass health and species distribution. The bay areas adjacent to Tagbilaran have significant number of houses, establishments, along with its proximity to roadways and a relatively large population likely induce a significant amount of disturbance and nutrient pollution to the marine environment. Besides, influencing low dissolved oxygen and perhaps high nutrient inputs from Abatan River. If the water column becomes hypoxic or anoxic during high degradation of organic matter in the sediments coupled with a stratified water column resulting in poor energy availability and production of toxic metabolites (e.g. sulphide), both of which may negatively affect the growth and survival of seagrasses (Greve and Binzer, 2004). A study modeled the effects of sediment characteristics on seagrass beds and found that fine grain sized sediment has a negative impact on seagrass shoot density due to decreased pore water exchange, leading to hypoxic sediment conditions (Folmer et al., 2012). Increasing siltation and the resulting changes to sediment conditions lead to diminished growing conditions for tropical seagrasses (Bach et al., 1998), while increased organic matter in sediments resulted in lower seagrass growth rates (Mascaro et al., 2009).

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Land use coastal vegetation was associated with the occurrence of species *H. uninervis* and *S. isoetifolium*. Relative abundance of these species was significantly higher in Panglao. Also, *Th* shoot density was significantly higher in Panglao. Thus, *T. hemprichii* associated with coastal vegetation resulted in increased shoot density. The higher shoot density can be due to low mortality or physical damage of *T. hemprichii*, as they are sheltered from direct impact from burial and erosion (Saenger et al., 2012; Guannel et al., 2016). The lower *Th* shoot density in Tagbilaran can be a result of increased silts and sediments resulting in shoot mortality or damage. This has been observed for seagrass population under sediment burial and erosion conditions (Cabaco et al., 2008; Saunders et al., 2017), which has been observed for *T. hemprichii* population of Philippines (Duarte et al., 1997). In the Philippines and SE Asia, one of the most significant threats to seagrasses includes increased siltation from deforestation (Fortes, 2001).

Marine protection did not have an effect on any of the environmental variables in the study. The result is similar to the study of Quiros et al. (2017). However, closed MPA had strong impact on seagrass condition. It showed close association with seagrass species *H. uninervis*, *S. isoetifolium* and *H. pinifolia*. The creation of protected areas is a well-established tool to reducing habitat loss and mortality from harvesting (Pimm et al., 2014) and there are more than 200,000 protected areas worldwide. However, up to 421.9 million people worldwide live near the borders of protected areas, resulting in over 83% of MPAs being highly impacted by humans (Mora and Sale, 2011). In the Philippines, Marine Protected Areas (MPAs) were established as fisheries management tools under the National Integrated Protected Areas System Act of the Philippines (NIPAS), the Fisheries Code of 1998 and the Local Government Code of 1991. This gave local governments the authority to manage their nearshore marine waters in cooperation with the national government (Russ and Alcala, 1999). However, MPAs in practice have a spectrum of management schemes and compliance to those schemes. In Maribojoc Bay, MPAs ranged from complete to incomplete protection. In this study, two MPAs had some level of fishing controls as these are enclosed with buoy markers and managed by sea guards “bantay-dagat”, whereas the other two MPAs had open access to fishing, gleaning and other beach activities.

In the coastal ecosystems, where there is land-sea interactions and land use practices such as land clearing for urban development, agriculture, and forestry have altered the composition and concentration of sediment, nutrients, organic carbon, contaminant, and disease fluxes from land to sea (Thrush et al., 2004; Tomasko et al., 2005; Crain et al., 2009). The effects of these alterations vary and may include decreasing light availability for photosynthesis (Bach et al., 1998), burial of benthic communities (Thrush et al., 2004), and changes in nutrient loading leading to increased eutrophication (Tewfik et al., 2007), leading to changes in seagrass community composition, productivity, and function (Orth et al., 2006). Similarly, Short et al. (2006) found that land-based human activities (tourist development, mangrove clearing, shoreline hardening) that altered sediment and nutrient fluxes to adjacent nearshore areas led to decreased seagrass percent cover in Placencia, Belize, and Freeman et al. (2008) found that seagrass loss both inside and outside of MPAs was due to decreased subsurface light intensity from a sediment plume caused by deforestation in the adjacent watershed.

Seagrass meadows, and the ecosystem services they provide, are decreasing all over the world (Waycott et al., 2009). One reason for the lack of management of seagrass ecosystem is the perception by local users that seagrasses are less vulnerable to threats

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by human activities and perceived as less important compared to coral reefs and mangroves (Fortes, 2008, 2012). This study demonstrates that a major impact to seagrass species density, species richness, percentage cover and total seagrass density is human activities occurring on land, particularly human development. Also, the effects of land use on coastal ecosystems have suggested the importance of the adjacent vegetation to seagrass integrity, leading to the suggestion that terrestrial conservation may be a better investment than marine conservation (Klein et al., 2010). Moreover, Quiros et al. (2017) found that land use associated with terrestrial protection had significant effects on seagrass richness and abundance, in which he proposed that land use is more important than marine protection for maintaining tropical seagrass condition.

Results of the study further demonstrate the complementary connection between land and sea, justifying the ‘ridge-to-reef’ approach in coastal conservation (Richmond et al., 2007; Rude et al., 2015; Teneva et al., 2016). However, coastal land use, fisheries and marine protected areas are generally managed by different sectors of society (Crowder et al., 2006). National and local plans for marine and terrestrial protection are emerging but for most part independent of one another. There may be significant and beneficial gains on seagrass condition by coordinating these conservation efforts. Therefore, implementing terrestrial protection as a tool for seagrass conservation would take increased cooperation and collaboration between terrestrial and marine conservation agencies and practitioners. In addition to that, legislation and planning programs need the support of educational campaigns, which can also provide the community with solutions for protecting seagrasses.

Conclusion

The present study provides a spatial data demonstrating that seagrass ecosystem in Maribojoc Bay was influenced by several environmental factors as well as land-use practices. Land-use related to human development had the most important impact on seagrass biological variables in the present study. Hence, the nature of coastal land is an important determinant of seagrass health and condition. Seagrass beds adjacent to human development showed lower seagrass density, species richness, percent cover and *Th* shoot density. It is therefore important to consider both marine and land-based strategies for mitigating declines in seagrass and degradation. The findings of this study suggest that mitigating human activities on land adjacent to seagrass communities is more important for maintaining seagrass biodiversity and land-based strategies can be a better tool for seagrass ecosystem protection. However, there is a need for further investigation on spatio-temporal changes of the variables in relation to seagrass ecosystem. It is recommended to have a time series analysis of satellite images using change detection software employing supervised classification techniques or similarly more complex techniques.

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