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Sustainable Aquatic Research (2024) 3(1):58-76
DOI: 10.5281/zenodo.11046358
e-ISSN: 2822-4140

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RESEARCH PAPER

Assessment of Benthic Macrofauna and Sediment Characteristics of Boracay Island Philippines

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Citation

Naciongayo, J.J.B., Santander-de Leon, S.M.S. (2024). Assessment of Benthic Macrofauna and Sediment Characteristics of Boracay Island, Philippines. *Sustainable Aquatic Research, 3*(1), 58-76.

Article History

Received: 12 October 2023
Received in revised form: 28 December 2023
Accepted: 28 December 2023
Available online: 30 April 2024

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Keywords

Benthic Macrofauna
Abundance
Distribution
Diversity
Sediments

Abstract

Boracay island is a world-famous beach located in the Philippines. Its beaches are economically important due to its unique "white sand" characteristics popular for swimming and other recreational activities. Studies on macrobenthic organisms and sediment characteristics in the area are still lacking. This study assessed the diversity, abundance, and distribution of the benthic macrofauna and the characteristics of the sediments in Stations 1, 2, and 3 of Boracay Island. Tide lines from various times of the day: high tide – morning (HTM), low tide (LT), high tide – evening (HTE); and at 0.5m water depth at high tide morning (0.5) were assessed. Overall, there were 474 individuals belonging to 5 classes, 10 families, and 10 genera collected from the three stations. The major taxa groups found were Bivalvia, Gastropoda, Malacostraca, Polychaeta, and Sipuncula. *Donax* sp. (wedge shell) was the most dominant species in the study area with 266 total individual counts. Among the three stations, Station 1 was the most diverse (H, 1.21) while Station 2 had the most abundant macrofaunal presence (relative abundance, 82.07%). In terms of area, HTE was the most diverse and abundant (H, 0.22; relative abundance, 60.97%). Most of the species found are known to be highly tolerant to wide conditions making it easier for them to adapt with less ideal conditions. The *Armandia* sp., found dominant in the area, is highly sensitive to marine pollution, making it an excellent indicator for future monitoring of Boracay Island and other similar sandy beaches.

Introduction

Sandy beaches is one of the most famous spots for tourist destinations, accommodating various human activities (Maguire et al., 2011). With this, beaches become one of the most exposed spaces to various physicochemical activities (Defeo & McLachlan, 2013). These exposed sandy beaches are categorized along a morphodynamic gradient, from dissipative to reflecting beaches. Reflective beaches are small, have rougher sand, a steeper slope, and have waves that crash along the front of the beach. Meanwhile, dissipative beaches are distinguished by finer sediments, a smooth slope, and a large wave breaking zone (Wright & Short, 1984). The difference in sediment composition of these beaches affects their ability to support particular biological groups (Alongi, 1990). Only a few taxa, predominantly crustaceans, can settle and flourish in harsh reflecting habitats where turbulent hydrodynamic regimes predominate, especially at supralittoral beach levels. As a result, sandy beach settlements are primarily shaped by their physical surroundings (Wright & Short, 1984).

Sandy beaches' biological communities can undergo various spatial and temporal scale changes (Defeo et al., 2009). According to Defeo et al. (2007), species identities vary between and within large geographic regions. The intertidal zone exhibits the widest distribution on a small scale, both vertically and horizontally, leading to a scattered dispersion of organisms especially of benthic macrofauna. Animals in the macrofauna class are categorized by their size. They often live in soft sediments, such as sands and muds, and occasionally gravel. These organisms can be obtained on a 0.5-1.0 mm mesh sieve and typically range from 1 mg to 2 g dry tissue weight. Benthic macrofauna resides on the top of the sediment (epifauna) or in the sediment (infauna). The study of Watling (2019) shows the majority of infauna live in the top few centimeters of the sediment due to their dependence on tiny organic particles that drop from the upper water column to the ocean floor. Furthermore, oxygen concentration is more abundant in the upper layers of the sediment. Their notable trait is a significant level of mobility, which includes the capacity to burrow quickly. The intertidal and surf zones of beaches include populations of these species that change through time. Although polychaete worms, mollusks, and crustaceans typically predominate, all major taxa are represented such as nemerteans, anthozoans, platyhelminthes, sipunculids, echiurans, insects, and echinoderms. Some of these taxa are restricted to protected beaches. In descriptions of sandy beaches, insects are frequently disregarded, but they can occasionally be the most numerous groups found on the shoreline (Cochran et al., 2019; McLachlan & Defeo, 2017).

It has long been understood that sediment properties have a significant impact on the composition and diversity of benthic infaunal populations (Gray, 1974). Numerous habitats and sizes have been investigated while examining the relationships between sediment properties and infaunal communities. It has been demonstrated that salinity, water depth, habitat shape, food abundance, and sediment grain size all affect the composition of infaunal populations (Lindegarth & Hoskin, 2001; Ellingsen, 2002). In the same manner, benthic macrofauna also have various impacts on the sediment's physicochemical properties. The activity of macrofauna is a crucial biological buffer against disturbances like excess organic matter and nutrient loadings, maintaining an oxidized upper sediment layer. In addition to preventing sediment dystrophy and sulfide release to the water column, it promotes mineralization and dissimilatory processes like denitrification. Macrofauna also expedites solute release and promotes benthic-pelagic coupling (Andersen & Pejrup, 2011). Moreover, seabed roughness and sediment buildup are both influenced by macrofauna. Animals usually cause the bed's roughness to intensify due to their own tubes or traces, which results in higher bed shear stress and the potential for bed erosion. Additionally, the macrofauna's eating and movement change how the sediment is accumulated, which has an impact on the sediment's erodibility (Nowell et al., 1981; Grant & Daborn, 1994).

One of the most well-known sandy beaches in the Philippines is Boracay Island, renowned for its crystalline blue ocean and fine white sand. Boracay is one of the top tourist destinations in the Philippines, which increases economic output, generates a large number of employment opportunities, improves infrastructure, and fosters cross-cultural interaction among visitors and locals. Due to its great socioeconomic worth, the island has been the focus of numerous scientific studies that have evaluated its water quality, nutrient intake, mangrove ecosystem, plankton dispersion, and many other factors. However, information about the presence of benthic macrofauna and the assessment of the sand's physicochemical characteristics is rarely available, which should have been given much attention because benthic macrofauna in sandy beaches is a good indicator of ecological status (Schlacher et al., 2008), especially in Boracay where it has become ecologically fragile and susceptible to pollution due to increased developments and tourism activities. With this, the study aims to assess the benthic macrofauna and the sediment characteristics of Boracay Island. Specifically, this aims to compare the diversity, abundance, and distribution of the benthic macrofauna in the three stations of Boracay Island as influenced by tide level, time, and area; and describe the sediment characteristics where the benthic macrofauna was observed.

Materials and Methods

In this study the diversity, abundance, and distribution of benthic macrofauna and sediment characteristics was assessed in the three stations of Boracay Island (Fig. 1). Samples from each station were collected from two areas: within the tide line (TL), and within the 0.5m water depth (0.5). Different sets of samples are also collected during the high tide - morning (HTM), low tide (LT), and high tide - evening (HTE). The macrofaunal samples were subjected for faunal identification, computation of diversity index; and total and relative abundance. Sediment samples were measured based on its salinity, redox potential level, sediment color and smell, total organic matter (TOM), and grain size.

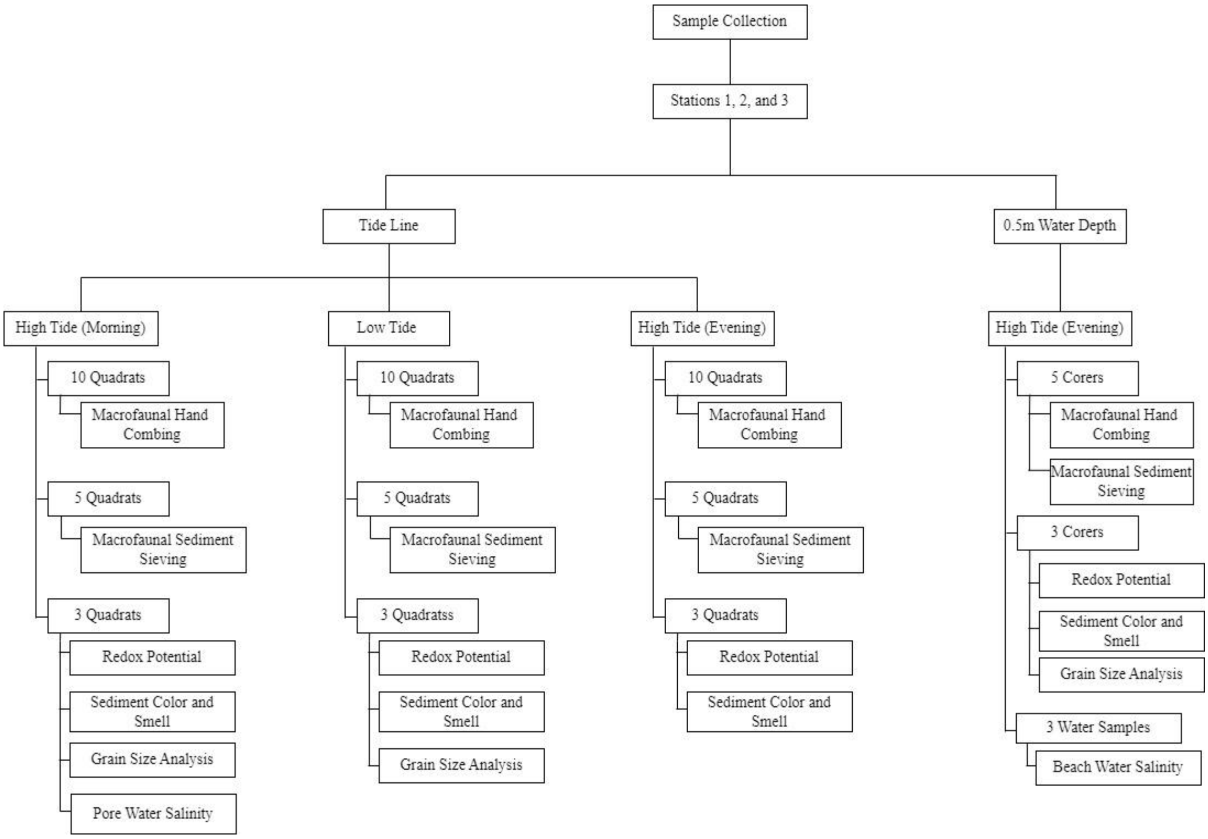


Figure 1. Sampling design for the assessment of benthic macrofauna and sediment characteristics in Stations 1, 2, and 3 of Boracay Island.

Description of Study Area

Boracay Island is situated in the Municipality of Malay, Aklan, northwestern tip of Panay, Western Visayas (Fig.2). The land mass has a maximum width of 3.3 km and a maximum length of 6.8 km, with greatest heights between 50-105 m above mean sea level. The total land area of Boracay Island is 1,006.64 hectares. The island is divided into three barangays - Manoc-Manoc, Balabag, and Yapak - and has over 17 beaches, with White Beach being the most popular (Limates et al., 2016).

The sampling sites of the study were located at the three stations (Figure 2). Station 1, with coordinates of 11° 58 '5.47"N Latitude and 121° 55' 7.08"E Longitude, is the farthest station from the Cagban Port (Boracay Port). According to classification, it has the best and finest stretch of white sands among all stations. This is also the station where the majority of the luxury hotels and resorts are located. Station 2, with coordinates of 11° 57 '39.43"N Latitude and 121° 55' 28.72"E Longitude, is located in the middle area of the beach. It is known as the busiest region of the beach because this is where most shops and restaurants are located. Station 3, with coordinates of 11° 57 '12.11"N Latitude and 121° 55' 44.51"E Longitude, is the nearest station from the port. This station houses mid-range and more affordable hotels and resorts (Morales, 2022).

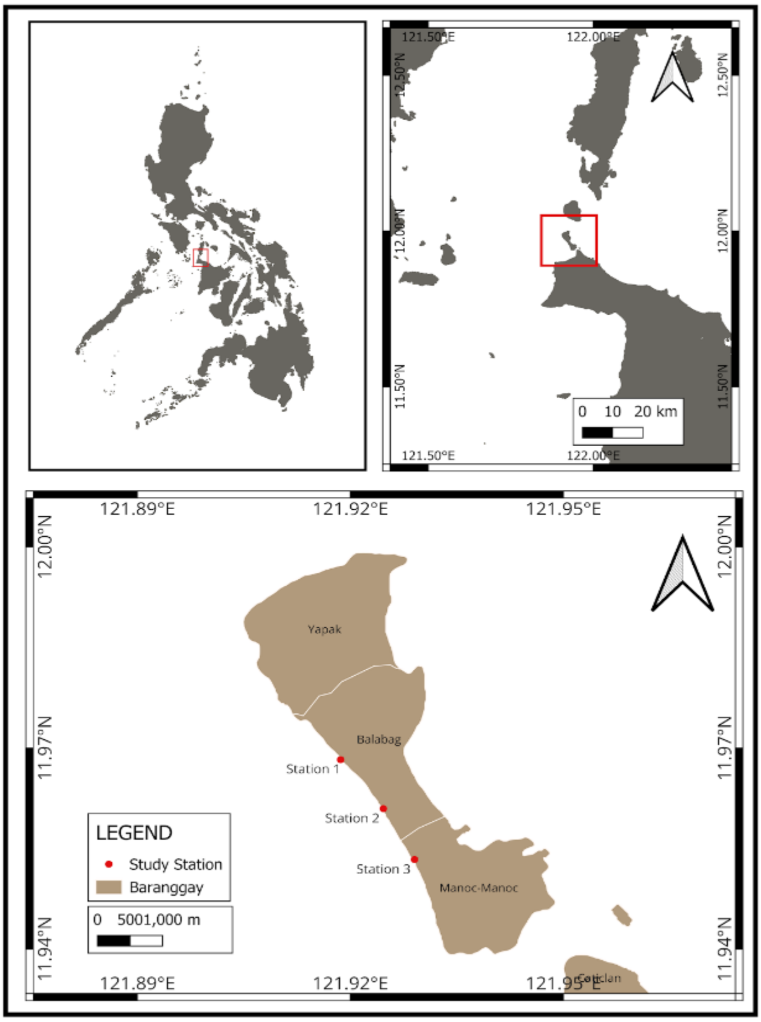


Figure 2. Map of Boracay Island indicating the three-sampling sites Stations 1, 2, and 3

Sampling Method

Sampling was was conducted in October 2022 in the three stations of Boracay Island. In each station, samples were collected in two different areas and at different points of the day to fully cover the occurrence and presence of the benthic organisms. The two different areas were within the tide line (TL) and at 0.5-meter water depth (0.5) while the different points of the day were one during the peak of high tide in the morning (HTM), one on the peak of low tide (LT) in the afternoon, and one on the peak of high tide in the evening (HTE). To collect the samples in the tide line, a 100-meter transect was placed within each station. Then 10 quadrats were equally distributed within the 100-meter distance. Each quadrat has a dimension of 0.5 x 0.5 meter. Samples were then collected within the quadrat using small shovels. To collect samples in the 0.5-meter water depth, a 100-meter transect was placed within the station. Then, 5 transect points were equally distributed within the given distance. In each point, a corer was used to collect the samples.

Macrofauna Collection

To collect the macrofauna in the tide line, two methods were used: hand-combing and sieving. For hand-combing, visible macrofauna within the top 5 cm layer of sediments were hand-picked and were manually counted. Then all collected macrofauna were placed in a container and were preserved with 10% formalin. For sieving, a depth of 5 cm of sediments were collected and were stored in a zip lock. In the laboratory, the sediments were sieved using a stack of 5 mm, 3 mm, 2mm, 1mm, and 0.5 mm sieve mesh. All sieved macrofauna were then preserved with 10% formalin. All the collected samples from two methods, hand-combing & sieving, were combined to get the total individual count per area and station.

To collect the macrofauna at 0.5m water depth, a corer was pushed directly into the sediment at 15 cm depth. Then, the corers were retrieved and observed if visible macrofauna was found. After that the sediments were transferred to a clean basin and were homogenized. A subsample of the homogenized sediment was then kept to be used for macrofaunal sieving. All visible macrofauna in the corer and those collected from the sieve were combined to get the total individual count per area and station.

For the identification of these samples, all collected macrofauna were initially sorted into major taxonomic groups. They were then placed in separate sample vials with identification labels. Taxonomic guides and literatures were used to identify each group at the lowest taxonomic level possible.

Sediment Characteristics

Sediment colors were analyzed using Munsell Soil Color Chart. The depth at where the sediment changed in color was also recorded. Black sediment with rotten egg smell was observed for the presence of hydrogen sulfide. Redox potential was measured using a redox meter (Horiba) where its Ag/AgCl probe was inserted in the top 1 cm layer of the sediments in the quadrat or core. For samples with both white and gray colors, both layers were measured for redox. Values were corrected with +150 mV. The salinity of the sediment was determined by excavating the sediments close to the tide line until pore water was visible. The pore water was filtered in situ using a plankton sieve to remove sediments. Then the filtered pore water was placed in the refractometer to determine salinity.

For grain size analysis, sediments were collected using small shovels or corer. Samples were homogenized before they were kept in airtight plastic bags. Samples were then brought to the laboratory for sieving. For dry sieving, 25 g of the sample was weighed and was dried in the oven for 24 hours at 110 degree Celsius. Samples were then transferred to the desiccator and cooled for 15 minutes. The samples were then added on a sieve stack with mesh sizes of Wentworth Scale classifications as follows: 5.66 mm, 4.76 mm, 3.36 mm, 2.83 mm (Granule); 1.41 mm (very coarse sand); 0.84 mm (coarse sand); 0.350 mm (medium sand); and 0.053 mm and 0.037 mm (coarse silt) (Holme and McIntyre, 1984). The weight for all fractions were recorded.

To measure for TOM, 3g of samples were dried for 24 hours in the oven at 80 degree Celsius then placed in the desiccator to cool. Samples were weighed. Combustion was done using a furnace for eight hours at 500 degree Celsius transferred in desiccator and weighed. The difference in the weight of the sample prior and after combustion was recorded as the total organic matter content of the samples.

Data Analysis

Mean values were calculated for salinity level, redox potential, and TOM in three different stations. Diversity index was computed using the formula of Shannon-Wiener Index (H) and Percent Relative Abundance (R) using the formula below:

$$H = p_i * ln(p_i)$$

where

H = Shannon-Weaver diversity index

p_i = the proportion of individuals (n/N) of one species (n) divided by the total number of individuals found (N)

ln = Natural logarithm

Σ = Summation from the first species to the last

$$R = \frac{n}{N} x100\%$$

where

R = percent relative abundance

n = Number of individuals of one species

N = Total number of individuals found

One-way ANOVA and Independent T-test were used to assess significant differences in sediment characteristics including salinity, total organic matter, and redox potential. Post Hoc Test was performed in the results of TOM to further quantify the observed differences.

Results and Discussions

Distribution, Abundance, and Diversity of Benthic Macrofauna

The distribution of the individual species collected from the study area presents the occurrence of the collected macrofauna based on tide level, time, and area (Table 1). It was observed that various taxa reside in each station and certain species are only present in particular locations during a specific time. For instance, during HTM, no macrofauna was observed in both Station 1 and Station 3, but a few gastropoda, specifically, *Monetaria* sp. (Cowrie) were collected in Station 2. During the LT, bivalvia, gastropoda, and polychaeta are observed in Station 1 and Station 2 while malacostracans like *Emerita* sp. (Pacific Mole Crab) and Ocypodidae (Ghost Crab) are seen to be settling in Station 3. It can also be noted that there are certain genera of polychaetes such as *Aonides* sp. and *Nephtys* sp. and bivalves like *Pinctada* sp. (Sea Mussel) that are observed in Station 1 but are not present in other stations. During the HTE, *Donax* sp. (Wedge Shell), *Nassarius* sp. (Nassa Mud Snails), and *Armandia* sp. are abundantly observed in both Station 1 and 2. Meanwhile, in Station 3, only Ocypodidae species are found. Ocypodidae are also found in Station 2 but none have ever been observed in Station 1 over the whole sampling period. A species from the class Sipuncula was also found solely in Station 1. Lastly, only one species of macrofauna was observed at 0.5m and was collected in Stations 1 and 2. This species was identified to be *Armandia* sp. and can also be observed in the tide line area.

Table 1. Distribution and composition of macrofauna in Stations 1, 2, 3 of Boracay Island. HTM = High Tide in the Morning, LT = Low Tide, HTE = High Tide in the Evening.

		Station 1	Station 2	Station 3
Tide Line	HTM		Gastropoda: *Monetaria* sp.	
	LT	Bivalvia: *Pinctada* sp. Gastropoda: *Nassarius* sp. Polychaeta: *Armandia* sp. *Aonides* sp. *Nephtys* sp.	Gastropoda: *Nassarius* sp. Polychaeta: *Armandia* sp.	Malacrostaca: *Emerita* sp. *Ocypodidae*
	HTE	Bivalvia: *Donax* sp. Polychaeta: *Armandia* sp. Sipuncula	Bivalvia: *Donax* sp. Malacostraca: *Ocypodidae*	Malacostraca: *Ocypodidae*
at 0.5m Water Depth		Polychaeta: *Armandia* sp.	Polychaeta: *Armandia* sp.	

The summary of abundance and diversity index of macrofauna in the three stations are shown in Table 2. In Station 1, most benthic macrofauna appeared in LT with a total of 49 individuals and a relative abundance of 77.89% while the least abundant area was observed in HTM with 0 individual counts and 0 relative abundance. The table also shows that the dominant genera in this station is *Armandia* sp. with a total count of 39 individuals and most of them also appeared during the low tide. Meanwhile, the least dominant species include *Pinctada* sp., *Aonides* sp., and *Sipuncula* sp. which only have 1 total count for each species. In Station 2, it can be observed that most benthic macrofauna appeared during HTE with a total of 261 individuals and a relative abundance of 67.10% while the least abundant was observed to be during HTM with only 2 individuals and a relative abundance of 0.51%. The table also shows that the most dominant species in this station is the *Donax* sp. with a total count of 257 which are only found during the evening. Meanwhile, the least dominant species in this station is the *Monetaria* sp. with a total of 2 individuals. In Station 3, most benthic macrofauna can be found during HTE with a total individual count of 17 and a relative abundance of 77.27 % while no macrofauna was observed during HTM and at the 0.5m. The table also suggests that the dominant species in this Station is Ocypodidae while the least dominant is *Emerita* sp. with a total count of 21 and 1, respectively.

Table 2 also shows the comparison of abundance per station and per area and time. This indicates that in terms of station, Station 2 is the most abundant with a total of 389 individuals and a relative abundance of 82.07% while Station 3 is the least abundant with only 22 individuals and a relative abundance of 4.64%. In terms of area, most macrofauna appeared in the HTE with a total of 289 individuals and a relative abundance of 60.97% meanwhile the least benthic macrofaunal presence was observed in the HTM with a total count of 2 individuals and a relative abundance of 0.42%. Furthermore, *Donax* sp. dominated the three stations with a total count of 266.

In terms of area, all stations show low diversity, with HTE having the highest diversity with H = 0.22, based on the Diversity Index Criteria (Table 3). However, the diversity index per station shows that Station 1 is moderately diverse with a diversity index of 1.21 while Stations 2 and 3 remain to be at low diversity with Station 3 being the least among the three of them with only 0.18 diversity index.

Table 2. Occurrence, Composition, Relative Abundance, and Diversity Index (H) of benthic macrofauna in Stations 1, 2, 3 of Boracay Island

Class	Genus	Species	Station 1					Station 2					Station 3					Over-all
			HTM	LT	HTE	0.5	Total	HTM	LT	HTE	0.5	Total	HTM	LT	HTE	0.5	Total	Total
Bivalvia	*Donax* sp.	Sp1	-	-	9	-	9	-	-	257	-	257	-	-	-	-	-	266
	Pinctada sp.	Sp2	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-	1
Gastropoda	*Monetaria* sp.	Sp1	-	-	-	-	-	2	-	-	-	2	-	-	-	-	-	2
	Nassarius sp.	Sp2	-	4	-	-	4	-	3	-	-	3	-	-	-	-	-	7
Malacrostaca	*Emerita* sp.	Sp1	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	1
	Ocypodidae	Sp2	-	-	-	-	-	-	-	4	-	4	-	4	17	-	21	25
Polychaeta	*Aonides* sp.	Sp1	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-	1
	Armandia sp.	Sp2	-	35	1	3	39	-	119	-	4	123	-	-	-	-	-	162
	Nephtys sp.	Sp3	-	8	-	-	8	-	-	-	-	-	-	-	-	-	-	8
Sipuncula	Sp1	Sp1	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-	1
Total			-	49	11	3	63	2	122	261	4	389	-	5	17	-	22	474
Relative Abundance per Area			-	77.78%	17.46%	4.76%	100%	0.51%	31.36%	67.10%	1.03%	100%	-	22.72%	72.27%	-	100%	
Diversity Index (H') per Area			-	0.88	0.60	0	-	0	0.16	0.08	0	-	-	0.50	0	-	-	
Relative Abundance per Station			13.29%					82.07%					4.64%					
Diversity Index (H') per Station			1.21					0.51					0.18					

Table 3. Diversity Index Criteria by Wibowo et al., (2021) used to assess the diversity status of macrofauna in Stations 1, 2, and 3 of Boracay Island.

Value of H'	Indication
H'≤1	Low Diversity
1≤H'≤3	Moderate Diversity
H'≥3	High Diversity

The abundance per species in each station is also presented in Tables 4-6. As shown, *Armandia* sp. is the most abundant species in Station 1 with 61.90% abundance while *Pinctada* sp., *Aonides* sp., *Nephtys* sp., and Sipuncula are the least abundant with 1.59%. For Station 2, *Donax* sp. is the most abundant species with 66.06% relative abundance while *Monetaria* sp. is the least abundant. For Station 3, Ocypodidae is the most abundant species with 95.45% abundance while *Emerita* sp. is the least abundant with 4.5% abundance.

Table 4. Total abundance of individual species and their relative abundance in Station 1, Boracay Island. Ind=Individual.

Class	Genus	No. of Ind	Relative Abundance (%)
Bivalvia	*Pinctada* sp.	1	1.59
	Donax sp.	9	14.29
Gastropoda	*Nassarius* sp.	4	6.35
Polychaeta	*Armandia* sp.	39	61.90
	Aonides sp.	1	1.59
	Nephtys sp.	8	12.70
Sipuncula	Sp1	1	1.59
Total	**7**	**63**	**100**

Table 5. Total abundance of individual species and their relative abundance in Station 2, Boracay Island. Ind=Individual.

Class	Genus	No. of Ind	Relative Abundance (%)
Bivalvia	*Donax* sp.	257	66.06
Gastropoda	*Monetaria* sp.	2	0.51
	Nassarius sp.	3	0.77
Malacostraca	Ocypodidae	4	1.03
Polychaeta	*Armandia* sp.	123	31.62
Total	**6**	**389**	**100**

Table 6. Total abundance of individual species and their relative abundance in Station 3, Boracay Island. Ind=Individual.

Class	Genus	No. of Ind	Relative Abundance (%)
Malacostraca	*Emerita* sp.	1	4.55
	Ocypodidae	21	95.45
Total	**2**	**22**	**100**

The benthic macrofauna of sandy beaches comprises members of numerous phyla, although crustaceans, mollusks, and polychaetes are typically dominant and can be separated into intertidal and supralittoral forms (Brown & McLachlan, 1990). These macrofauna are influenced by the tidal cycle, wave pattern, and sediment composition (Defeo & McLachlan, 1991). Previous assessment of the benthic macrofaunal assemblages in the southern beaches of Philippines also shows the occurrence of sipuncula, polychaetes, and bivalves in the study area (Leopardas et al., 2014). In a study conducted in west portion beaches of Guimaras, Philippines most macrobenthic invertebrates include hard and soft coral, gastropods like cowrie, bivalves, and malacostracans. These organisms live in sandy-silty types of substrates with salinity range of 28-30 ppt (De La Cruz et al., 2012). These observations are also parallel to the results of this study which shows the occurrence of the same classes of benthic macrofauna.

The benthic macrofauna living in these sandy sediments are essential for the mixing, ventilation, oxygenation, and irrigation of sediments (bioturbation) (Meysman et al., 2005; Snelgrove et al., 2018). The bioturbation activity enhances benthic-pelagic connection, substrate permeability, food resource redistribution, buffering against nutrient enrichment, and nutrient cycling (Kristensen et al., 2012). The chemical reactions in general such as redox potential are positively influenced and the depth of the oxic layer is extended over the anoxic one (Koike & Mukai, 1983; Snelgrove et al., 2018).

The high productivity of certain sandy beaches is mainly due to the density of interstitial fauna. Species diversity is usually low and confined to a few species of polychaetes, molluscs, and crustaceans. Among the invertebrates, molluscs are the most important taxa in terms of biomass (McLachlan, 1983). The ecological dominance of some species depends on various factors such as environmental parameters, competition or the physiological and behavioral adaptations of these species. Bivalves of the genus *Donax* are an important constituent of the fauna of sandy beaches. Because of their physiological makeup, they can stay in the intertidal zone and reduce their risk of stranding and desiccation (Ansell et al., 1980). They tend to be particular about their substrate, therefore they only dig in sand with an appropriate grain size. These bivalves burrow more quickly as grain sizes get smaller thus significant numbers of this species are observed where grain sizes are smaller (De La Huz et al., 2002). Furthermore, *Donax* sp., specifically *D. trunculus*, has resistance to low and high salinity levels (Neuberger-Cywiak et al. 1989). The majority of bivalve species can also endure anoxic environments by lowering metabolic energy expenditures (Yusseppoine et al, 2018). Another feature of bivalve is the presence of alternate oxidase in their mitochondria which renders bivalves tolerant to hydrogen sulfide and low redox potential (Fenchel & Finlay, 1995). A prior study explored the distribution of *Donax* sp. which demonstrates that in response to regular and seasonal environmental fluctuations such as tides, waves, and currents, they typically undergo patchy but aggregated distribution (Neuberger-Cywiak et al., 1989). Interspecific competition with *Emerita* sp. may have contributed to the aggregated pattern in *Donax*. A patchy distribution may also be the result of other interactions with other organisms (Leber 1982).

Patchy distribution is also observed in filter feeders such as polychaete worms for the same reasons. Polychaete worms like *Armandia* sp., *Aonides* sp., and *Nephtys* sp. generally favor fine sands with little to no mud content for their habitats. Since a compacted substrate or low porosity hinders their capacity to burrow, these species, especially the *Armandia* sp., are extremely sensitive to sediment textures (Saes et al., 2018). These marine worms can also tolerate lower salinities up to 20 ppt (McLachlan & Brown 2006; Woodin, 1974). Additionally, the majority of polychaete species probably aren't extremely resistant to hypoxia, but they have life-history traits that make it possible for them to quickly adapt after better oxygen conditions. For instance, family of polychaete worms such as the Spionid reveals that it can endure severe episodes of hypoxia for at least two weeks without suffering any significant mortality (Llansó, 1991). Additionally, in the work done by Saes et al. (2018), species from the genus *Armandia,* notably the *Armandia agilis*, were tested as model organisms for sediment toxicity assessments. The outcome shows that *A. agilis* responses are comparable to other sensitive benthic animals revealing that this polychaete is responsive to contaminated sediments and may not be a pollution tolerant. With this, the abundant presence of *Armandia* species in the study area may indicate the current environmental health status of the island.

Gastropods like *Monetaria* sp. and *Nassarius* sp., are also among the benthic macrofauna that usually resides in the intertidal zones. Generally, gastropods are one of the most competitive scavengers on sandy beaches. Species like *Nassarius* sp. plays a crucial part as a cleaner of an area (Morton, 1994). Like bivalves, these gastropods also reside in finer sand, typically 2mm or less grain sizes, as they don't burrow well in larger sediment sizes. Previous studies on physiological energetics of *Nassarius* sp. also have shown that this species is tolerant to environmental stresses, including low salinity and hypoxia (Morton, 1997). However, continuous exposure to such stress increases susceptibility of gastropods with diseases (Wittmann & Pörtner, 2013).

A distinct species that was discovered along the tide line of Station 1 can be traced into the class of

Sipuncula. Sipuncula is also considered as a marine worm, however, unlike polychaetes, this species is unsegmented. Many of the sipunculan worms live in soft substrates and are deposit feeders. They frequently reside inside the shells of specific molluscs or the unfilled tubes of polychaetes and mostly play a role as significant bioturbators. Sipuncula are rarely abundant, yet occasionally they can dominate other species. In the study conducted by Ferrero-Vicente et al. (2011), there is a negative link between the quantity of sipuncula and fine sand and a substantial positive correlation between medium sand. There are also few investigations on the reaction of sipunculans to rapid changes in salinity and organic matter. However, some species have been found to have osmoconformers with limited ion regulating abilities in response to salinity change events (Chew et al., 1994).

Unlike the above mentioned macrofauna, malacostracans like *Emerita* sp. and Ocypodidae can withstand coarser sediments because of their burrowing mechanism and locomotory abilities (Lastra et al., 2002). The study of Dugan et al. (2004) also observed that crabs dug faster in coarser sand and slower in finer sand, contrary to the theory that *Emerita analoga* is a generalist in terms of sediment. The study also noted that while grain size affects burrowing speed, it has no immediate impact on crab mortality. A defining ecological trait of this class is its fossorial habit where the crabs excavate deep, voluminous and complex burrows alternating between activity on the beach surface and underground. They also have evolved to a range of physiological, morphological, and behavioral adaptations which results in the increased tolerance in fluctuating environmental parameters. Decapod crabs can endure a wide range of salinity but their survival rate is optimal at salinity level of 30 ppt and higher (Varadharajan et al. 2013). These species also flourish in areas with higher organic matter content as revealed in the study of Frusher et al. (1994). According to Rahim et al. (2021), crabs actively aid in the cycling of organic matter as these crabs bury the organic matter in the sediments.

Sediment Characteristics

The sediments in the three stations of Boracay were subjected to different parametric tests such as color, smell, salinity, redox potential, total organic matter content (TOM), and grain size analysis. The results revealed that sediments in the sampling area have two distinctions: white and odorless sand, and gray and sulfide-smelling sand (Figure 3). The sulfide odor was described to smell like a rotten egg. Generally, the sediments in Boracay are white and odorless. However, in Station 1 and in some parts of Station 2 (at low tide line and 0.5m water depth), sediments start to change in color and smell 5 cm below the surface.

Pipes partly buried in the sand were observed in the sampling areas. Previous reports of inadequate sewage and wastewater management systems is one of the prevalent issues in Boracay island. Wastewater discharge may have a negative impact on the ecosystem, such as reducing aquatic biodiversity, altering the color and smell of sediments (Peng et al., 2021).

A B

Figure 3. Collected sample of white and odorless sand (A) and gray and sulfide-smelling sand (B) in Boracay Island.

Figure 4A presents the results of the in-situ measurement of the salinity of beach water which was collected from the 0.5m water depth and pore water which was collected from the sediment in the tide line. Among the three stations, Station 1 has the highest beach water salinity level with 32.33 ppt while Station 3 has the lowest salinity with only 30.33 ppt. However, with regards to pore water salinity, Station 2 has the highest salinity level while Station 1 has the lowest salinity level with 24 ppt and 20.33 ppt, respectively. One-way ANOVA was used to determine whether there is a difference between mean values in each station and the p values show no significant difference for all stations. Over-all, beach water salinity has an average of 31.22 ppt and a range from 30.33 ppt - 32.33 ppt. Meanwhile, pore water salinity has an average of 22.55 ppt and a range from 20.33 ppt – 23.33 ppt. These indicate that pore water salinity is slightly lower than beach water salinity. An independent T-test was used to test if there is a significant difference between the salinities in beach water and pore water. The result shows a p-value of 0.002 indicating that there is a significant difference between the two.

The normal range of salinity for sandy beaches is between 30-35 ppt. Waska et al. (2021), also mentioned that salinity level decreases in deeper sediment depth which suggest that seawater has higher salinity level than beach porewater. This particular trend is observed in the result of this study where the salinity level of beach water is higher than that of pore water. Changes in salinity can be observed when there is a change in some ecological parameters such as the fluctuation of climate conditions because of low and high pressure or the runoff of freshwater and sewage (Wear et al., 2021). The study of Lercari & Defeo (2006), shows that with higher salinity, species richness was also evidently higher and it significantly decreased when the salinity range also decreased.

For the redox potential of white sand, results are summarized in Figure 4B. In Station 1 and 2, redox is highest at 0.5m with 938 mV and 974.67 mV, respectively and lowest in LT with 376 mV and 436 mV. For Station 3, redox is highest at HTM and lowest at LT with 896.67 mV and 726 mV. Over-all, Station 3 has the highest redox while Station 1 has the lowest with 826 mV and 704.41 mV, respectively. In terms of area, 0.5m has the highest redox with 923.56 mV while LT has the lowest with 512.67 mV. One way ANOVA was also used to test if there is a significant difference among the areas in each station, the p-values ($p = 0.179$; $p = 0.185$) show no significant difference in HT and 0.5m. However, a low p-value in the LT ($p < 0.001$) suggests that there is a significant difference among the three stations in this area. Thus, to further investigate this difference, a Tukey Post-Hoc test was performed which later revealed that the difference can be observed between Station 1 and 3 and Station 2 and 3.

Figure 4C summarizes the redox potential for gray sand. In Station 1, the highest redox is at 0.5m with 702.67 mV while lowest at LT with 149.33 mV. In Station 2, redox is highest at 0.5m with 855.33 mV and lowest at LT with -9.67 mV. No data was recorded for Station 3 because there was no observed gray sand in the area. Overall, the highest redox potential was observed in Station 1 with 476.58 mV while Station 2 is the lowest with 422.83 mV. In terms of area, 0.5m is the highest and LT is the lowest with 779 mV and 69.83 mV, respectively. White sand redox potential is greater than the gray sand at $p<0.008$.

Positive value of redox potential (+1 mV to 100 mV) indicates aerobic sediment or oxic conditions and larger benthic fauna accumulation while negative values (< -100 mV) indicate anaerobic sediments or anoxic conditions which contributes to the decline in environmental condition thus limiting biological processes (Holmer et al. 2005). High redox potential gradient is taken advantage of by a diverse microbial community in an undisturbed sediment. For instance, the top few millimeters of sediment, where oxygen is abundant and redox potentials are high, is inhabited by aerobic bacteria and other aerobic organisms. As the redox potential drops farther down, the aerobic organisms will no longer be observed and are replaced by fermenters. Anaerobic respiration takes over when the soil gets less oxygenated (McLachlan et al., 1979). Poorly oxygenated sediments can also occur in sandy beaches characterized as gray or black color sediment and emit a rotten egg smell of Hydrogen Sulfide (H_2S) (Burone et al. 2003). Previous study revealed that gray sand with rotten egg smell has lower redox potential (McLachlan et al., 1979). These observations are parallel to the result of the study which revealed that as sediments change from white sand to gray sand, the redox potential decreased with rotten egg smell, characteristics of anoxic conditions.

The TOM results are summarized in Figure 4D. In Station 1, TOM is the highest at 0.5m and lowest in LT with 1.38% and 0.87% respectively. In Station 2, TOM is highest in LT with 1.68% and lowest at 0.5m with 0.98%. Meanwhile in Station 3, TOM is highest in HT and lowest in LT with 3.42% and 2.94%. Overall, TOM is the highest at 0.5m with a mean percentage of 1.92% while lowest in LT with a mean percentage of 1.83%. In terms of station, Station 3 has the highest TOM for all areas with mean percentage of 3.26% while Station 1 has the lowest TOM in all areas with 1.09%. Results show $p < 0.05$ for all areas suggesting that there is a significant difference between the three stations.

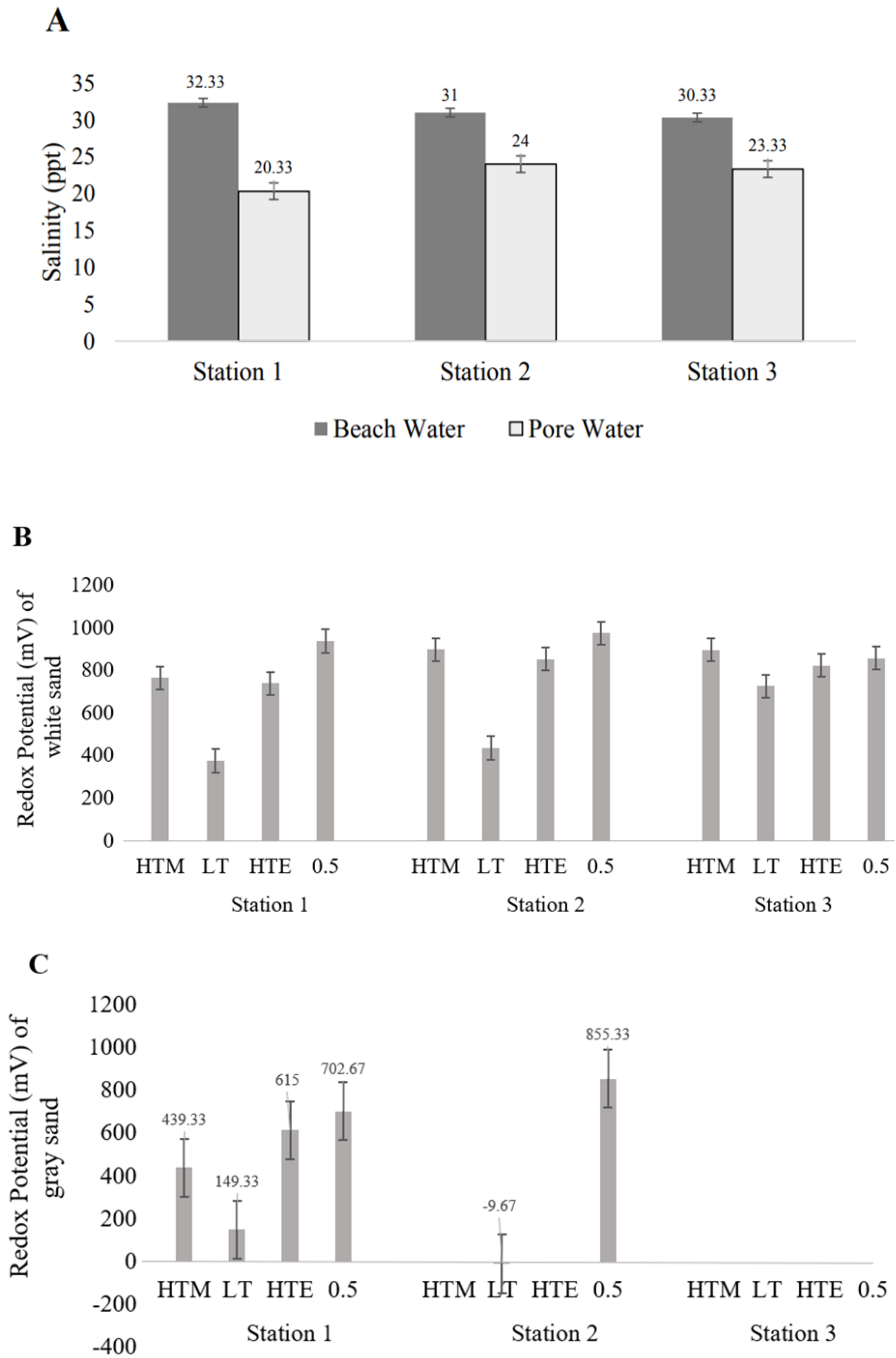
A number of factors, including sedimentary characteristics, the rate of microbial degradation, column water productivity, and terrestrial inputs, affect the amount of organic carbon in surface sediments (Burone et al., 2002). The density of meiobenthic fauna is characterized by organic matter concentrations (Gierre, 2009). An increase in organic matter in sediments promotes the richness and diversity of many organisms (Lercari and Defeo, 2003). However, there is a community shift if there is a presence of high total organic matter especially in sandy beaches where most species are under aerobic processes and prefer oxic conditions. High TOM stimulates anaerobic processes which is less ideal for sandy beach species. Thus, in this context, TOM is inversely related to the abundance of beach organisms (Khan et al., 2012). This is further supported by another study which states that TOM is negatively correlated with redox potential because the aerobic bacteria involved with the absorption of dissolved oxygen in the breakdown of organic matter depletes oxygen which results in lower redox potential level (Xia et al., 2022). It was also observed that the concentrations of organic matter were much higher on protected beaches than on exposed ones, and the protected beaches' low hydrodynamic conditions encouraged the accumulation of sedimentary organic matter (Incera et al., 2003). These findings corroborate the study's result which shows a low diversity and abundance in Station 3 and at 0.5 where TOM was recorded to be the highest.

For grain size analysis, each station shows a varied dominant proportion of sizes. Figure 4E shows that coarse silt has the highest percentage in all areas of Station 1, with a mean percentage of 82.57%, 94.53%, and 72.29% for HT, LT, and 0.5m respectively. Station 1 is mostly covered with coarse silt with a total percentage of 83.13%. Silt is a granular material between sand and clay which means that the sand in Station 1 is very fine.

On the other hand, the grain size analysis in Station 2 suggests a variation in size per area. For instance, in HT and 0.5m, most of the sediments are classified as medium sand with a mean percentage of 52.61% and 43.93%. While in LT, most sediments are coarse silt with a mean percentage of 81.72%. This shows a trend where sediments go from coarse to fine to coarse again. However, overall, Station 2 is still mostly composed of coarse silt with a total percentage of 45.75%.

Lastly, Station 3 has a lot of coarser sand compared to Station 1 and 2. The station is mostly covered with medium sand in HT and LT with a mean percentage of 57.97% and 51.74%. While coarse sand covers most of the area in 0.5m with a mean percentage of 35.33%. Over-all, Station 3 is dominated by medium sand with a total percentage of 47.06%.

Grain size has an influence on the diversity and number of species of macrofauna (Soto et al., 2017). According to the study of Rodil and Lastra (2004), the same pattern appears from exposed to very exposed sandy beaches where biomass of macrofauna decreases as the average grain size increases. These patterns are consistent with earlier research on several coastlines across the globe where coarse sands restrict the benthic macrofauna. Furthermore, the study of Barboza & Defeo (2015), mentioned that reduced sand particle size and wider, flatter beaches led to a large increase in species richness. At a worldwide level, species richness was mostly predicted by grain size and beach slope, which increased from reflective to dissipative beaches. This pattern is in line with the Swash Exclusion Hypothesis, which claims that species richness, abundance, and biomass steadily increase when circumstances shift from reflecting to dissipative. Because of the constancy of these patterns across the globe and the close connection between morpho dynamics and species richness at regional scales, it is possible to forecast the species richness of sandy beaches based on the physical characteristics of beach habitats.


A
Salinity (ppt)
35
30
25
20
15
10
5
0
32.33
20.33
31
24
30.33
23.33
Station 1
Station 2
Station 3
Beach Water
Pore Water
B
Redox Potential (mV) of white sand
1200
1000
800
600
400
200
0
HTM LT HTE 0.5
Station 1
Station 2
Station 3
C
Redox Potential (mV) of gray sand
1200
1000
800
600
400
200
0
-200
-400
439.33
149.33
615
702.67
-9.67
855.33
HTM LT HTE 0.5
Station 1
Station 2
Station 3

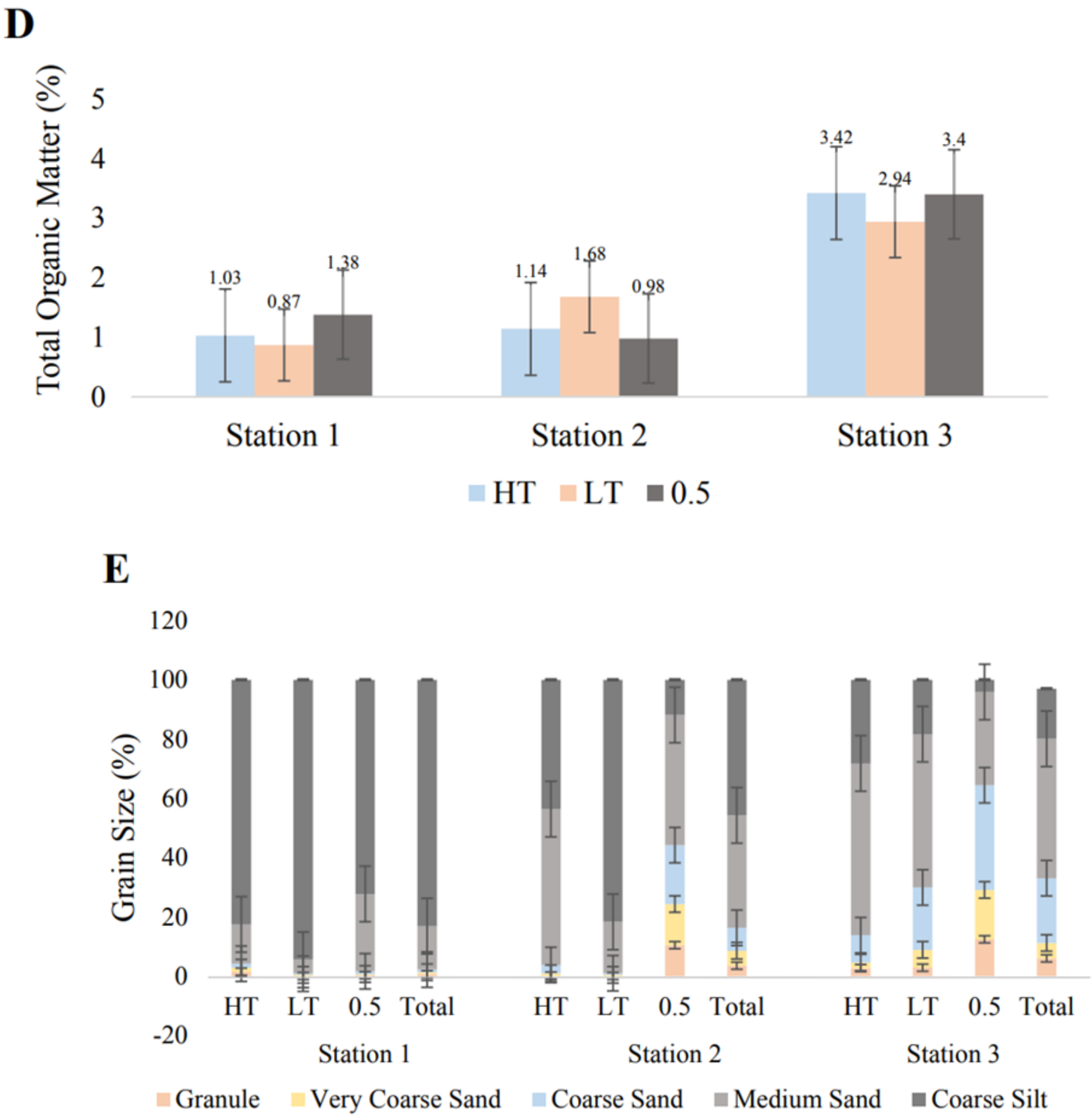


Figure 4. . Sediment Characteristics (A-E) in Stations 1, 2, 3 of Boracay Island. Values are mean and mean percentage (n=3). HT = High Tide, LT = Low Tide, HTM = High Tide in the Morning, HTE = High Tide in the Evening, 0.5 = 0.5m Water Depth

Benthic macrofaunal composition, structure, and distribution are highly influenced by the sediment characteristics. For instance, most of the benthic macrofauna, such as the bivalves, polychaetes, and gastropods, reside in Stations 1 and 2, specifically in the low tide line because these are the areas in the site with smaller sediment sizes. Finer sediments make the burrowing capacity and the locomotion activities of these species faster and more efficient. Meanwhile, malacostracans mostly occurred in station 3 and at 0.5m water depth because their mobility is quicker in bigger grain sizes. Living in a sandy beach where there are fluctuating environmental conditions and high exposure predators and other anthropogenic activities, these species need to develop fast burrowing behavior to protect themselves. Furthermore, diversity and abundance of species is higher in Station 1 and Station 2 where TOM is lesser. TOM stimulates anaerobic processes which are less ideal with beach organisms which live through aerobic processes and in oxic conditions. The result of the redox potential level in this area also shows high positive values which indicates that the sediments are in oxic conditions. However, there are also areas in the sampling site, notably in Station 1 and 2, that contain gray sand with sulfide odor and a comparatively lower redox potential which could indicate anoxic conditions that are still inhabited by some benthic macrofauna, commonly by *Donax* sp. and *Armandia* sp. These two species are also found to be the top two most abundant species in the whole sampling area. The dominance and occurrence of these species may be attributed to their ability to thrive in both anaerobic and aerobic conditions.

Conclusion

The study showed the benthic macrofauna composition and distribution in the sandy beach of Boracay Island; as well as the sediment characteristics where these benthic macrofauna reside. Overall, there are 474 individuals belonging to 5 classes, 10 families, and 10 genera collected from the three stations. The major taxa groups found are Bivalves, Gastropods, Malacostracans, Polychaetes, and Sipuncula. *Donax* sp., under the class of Bivalvia, was the most dominant species in the study area with an overall count of 266. Some taxa were only observed in some stations and areas at a certain period of time. Pore water salinity only measured at 23.33 ppt. Gray and sulfide-smelling sand were present in all areas of Station 1 and in some parts of Station 2, starting from 5 cm below the surface. The dominance of some species can be attributed to their ability to be non-selective and to thrive in anaerobic and aerobic conditions. Some of the macrofauna, specifically the *Armandia* sp., is also studied to be highly sensitive to marine pollution making it a good indicator of the health status of a certain study area.

Acknowledgements

The authors are grateful for the field assistance of Mr Joshua Bacunador.

Ethical approval

The authors declare that this study complies with research and publication ethics.

Informed Consent

Not Applicable

Conflict of interest

There is no conflict of interests for publishing this study.

Data availability statement

The authors declare that the data from this study are available upon request.

Funding organizations

N/A

Author contributions

JNaciongayo- Conceptualization, Sampling, Analyses, Writing, Editing

SSSantander-de Leon - Conceptualization, Sampling, Analyses, Editing

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