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Ecological Assessment of Macrobenthic Invertebrates in a Tidally Influenced Lagoon: A Case Study in Taguines Lagoon, Mahinog, Camiguin Island, Philippines

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Abstract

Macrobenthic invertebrates in Taguines Lagoon, Mahinog, Camiguin Island, Philippines were assesed using transect-quadrat method and physico-chemical parameters (temperature, pH, salinity and total dissolved solids) were measured. Results showed that there were a total of 23 species found in the lagoon dominated by *Cerithium* sp., *Diadema* sp., *Ostrea* sp., *Paguroidea* sp. and *Synapta* sp. The diversity level in all stations was similar and showed no significant differences.

Non-metric multidimensional scaling ordination highlighted that there is no clear segregation of species between stations. Cluster analysis also revealed that there is a close relationship of the samples from Station 1, Station 2 and Station 4. SIMPER analysis also showed that high dissimilarity percentages were observed in most stations and were largely contributed by *Ostrea* sp., *Cerithium* sp., *Synapta* sp., *Spongia* sp. and *Paguroidea* sp. CCA also revealed that the relationship of every species that are affected by the physico-chemical parameters and what are the parameters that are affecting them.

Introduction

Coastal lagoons are ecologically valuable ecosystems that serve as transitional zones between terrestrial, freshwater, and marine environments (Pérez-Ruzafa et al. 2011, 2019) and may remain permanently connected to the adjacent sea or become temporarily isolated by sedimentary barriers (Kjerfve 1994; Gönenç and Wolflin 2004). These habitats are characterized by dynamic environmental conditions, including fluctuating salinity levels driven by tidal movements and freshwater inflows (Gillanders and Kingsford 2002; Pérez-Ruzafa et al. 2019). The ecological significance of these ecosystems lies in their ability to support diverse biological communities, including macrobenthic invertebrates, which play crucial roles in maintaining ecosystem processes and functioning. Taguines Lagoon, located in Mahinog, Camiguin Island, Philippines, is an exemplary coastal lagoon where such dynamic processes occur. The interplay of tidal fluctuations and freshwater inputs creates distinct salinity gradients, shaping the structure and diversity of its aquatic life.

Macrobenthic invertebrates, which inhabit the bottom substrates of aquatic systems, play a vital role in maintaining ecosystem functions (Chowdhury et al. 2022). They are essential for nutrient cycling, the decomposition of organic matter, and sediment stabilization, while also serving as a crucial link in the transfer of energy to higher trophic levels (Asadujjaman et al. 2012; Mieszkowska et al. 2013). Moreover, these organisms are highly effective bioindicators for assessing marine ecosystems, as they respond quickly to both anthropogenic and natural pressures (Pocklington and Wells 1992; Dauer 1993; Pancucci-Papadopoulou et al. 1999; Beasley and Kneale 2001; Calow 2009; Tampus et al. 2012; Chowdhury et al. 2022).

Taguines Lagoon is a coastal lagoon situated in Benoni, Camiguin (9.13246^{o}N, 124.79425^{o}E) and generally consisted of fine and coarse sand (Jimenez et al. 2011). It exhibits dynamic spatial and temporal salinity variations driven by the interplay of tidal movements and freshwater inflow, creating a

complex mosaic of habitats that support diverse assemblages of macrobenthic invertebrates. The distribution of these organisms across salinity gradients offers valuable insights into their ecological preferences and tolerance ranges. Despite its ecological importance, research on the biodiversity of the lagoon and ecological dynamics remains limited. Beyond its ecological value, Taguines Lagoon plays a vital socio-economic role, supporting local fisheries that provide livelihoods and food security to nearby communities and fostering ecotourism through its scenic landscapes and rich biodiversity. However, this critical ecosystem faces mounting threats from human activities, including aquaculture expansion, infrastructure development, and pollution from domestic and agricultural sources. These pressures, combined with the scarcity of scientific data, underscore the urgent need for ecological assessments to inform sustainable management and conservation strategies.

Therefore, this study was conducted to address the knowledge gap by investigating the species composition and diversity of macrobenthic invertebrates in Taguines Lagoon, Mahinog, Camiguin Island, Philippines. Specifically, it aimed to determine the species composition, relative abundance and diversity of macrobenthic invertebrates; identify the distribution of macrobenthic invertebrates; and verify and identify the correlation between the environmental parameters and the biodiversity of macrobenthic invertebrates in the lagoon. By analyzing their spatial distribution in relation to salinity gradients, this research seeks to uncover the relationships between environmental factors and biological communities in a tidally influenced lagoon. The findings can be a source of baseline information for future monitoring efforts and contribute to the broader understanding of biodiversity patterns in coastal ecosystems. Furthermore, the outcomes of the study will have practical implications for the sustainable management of Taguines Lagoon, ensuring that it continues to provide essential ecosystem services while preserving its ecological integrity.

Materials and Methods

Study area

Sampling of macrobenthic invertebrates was conducted in Taguines Lagoon, a coastal water body with a circumference of approximately 1,500 meters, strategically situated in Mahinog, Camiguin Island, Philippines (Fig. 1). An ocular survey revealed various anthropogenic activities occurring within the lagoon, including aquaculture operations for species such as milkfish, tilapia, oysters, and green mussels; the presence of food establishments; a government office (Bureau of Fisheries and Aquatic Resources-Camiguin); recreational parks; and fishing activities. To facilitate the study, four sampling stations were established across the lagoon.

Field sampling of macrobenthic invertebrates

Field sampling was done using transect-quadrat method. Initially, a 20-m transect was placed parallel to the coast with 2-meter distance away from the shoreline and was replicated thrice in a 1-m interval

starting from the shoreline. Then, a quadrat (0.5 m x 0.5 m) was laid down alternately in every one meter and macrobenthic invertebrates present in the quadrat were then identified and counted. Unidentified samples were collected, placed in sample jars, preserved in a 95% ethanol and brought to the laboratory for further species identification.

Measurements of physico-chemical parameters

In-situ measurements of the physico-chemical parameters such as temperature, pH, salinity and total dissolved solids (TDS) were also done using a Waterproof Portable Meter Kit (Oakton Instruments, Singapore).

Data analyses

To determine which species is dominating the lagoon, relative abundance was calculated using Microsoft Excel (2016). Diversity indices such as species richness (S), species evenness (J'), and Shannon-Wiener diversity index (H') were also analyzed using Paleontological Statistics Software Package (PAST) version 2.17c (Hammer et al. 2001). One-Way Analysis of Variance (ANOVA) was also performed to compare the diversity indices and environmental variables between stations, followed by Tukey's test using Statistical Package for Social Sciences (SPSS) v.21. Prior to analysis, normality distribution and homogeneity of the data were tested, and assumptions were met. Venn diagram was also developed using Venny v. 2.1 (Oliveros 2007–2015) to graphically and clearly show the distribution, similarities and differences of the biodiversity between stations of the lagoon.

The assemblages of macrobenthic invertebrates were analyzed using non-metric multi-dimensional scaling (nMDS) and cluster analysis based on square-root transformed abundance data. Transformed data were subjected to Bray-Curtis similarity measure prior to analysis. One-way Analysis of Similarity Percentages (SIMPER) was also used to determine which species contribute to the clustering and separation of samples while Canonical Correspondence Analysis (CCA) was done to identify the distribution of macrobenthic invertebrates in relation to different environmental parameters.

Non-metric multi-dimensional scaling (nMDS), cluster analysis, SIMPER were analyzed using Primer v.7.0 (Anderson et al. 2008) and CCA using PAST version 2.17c (Hammer et al. 2001).

Results and Discussion

Species composition and relative abundance

A total of 23 species were found and identified in the lagoon. Figure 2 shows the relative abundance of the invertebrate species found in the lagoon. Results revealed that *Cerithium sp.*, locally known as "tapusok", was the most abundant species with a relative abundance of 45.74%. This was followed by *Diadema* sp., *Ostrea* sp., *Paguroidea* sp. and *Synapta* sp. with a relative abundance of 14.24%, 11.07%,

9.31% and 4.56%, respectively. Other species found but were less abundant include *Perna viridis*, *Spongia* sp., *Monoplex pilearis*, *Ophiuroidea*, *Cirripedia*, *Patellidae*, *Echinometra mathaei*, *Holothuria* sp., *Thocus* sp., *Nerita* sp., *Anadara* sp., *Chiton sp.*, *Portunidae*, *Monetaria annulus*, *Tripneustes gratilla*, *Monetaria moneta*, *Bathybiaster loripes* and *Turbinidae*.

Cerithium species are abundant gastropods commonly found in marine environments and are widely distributed across various ecosystems (Nott and Nicolaidou 1990). Their ecological spread is influenced by a range of environmental factors, including temperature, salinity, pH, and total dissolved solids (Rumahlatu and Leiwakabbessy 2017). The presence of *Cerithium* species across all stations in the lagoon may be attributed to their ability to adapt to diverse substrates, such as sandy mud (Nott and Nicolaidou 1990). Their abundance could also result from a low number of predators, such as lobsters and fish, within the lagoon.

Several ecological and environmental factors further shape the distribution and recruitment of *Cerithium* species in lagoons, including sediment composition, wave exposure, salinity levels, and interactions with other organisms. For example, species like *Cerithium zonatum* display higher recruitment rates in coarse sandy sediments compared to finer sands, suggesting a preference for specific substrate types, though recruitment is not solely dependent on sediment composition (Skilleter and Underwood 1993). Environmental variables such as wave exposure, moisture fluctuations, temperature, and salinity create habitat gradients that define the niches where *Cerithium* species thrive (Ayal and Safriel 1980). Additionally, interactions with other organisms, such as epizoites on their shells and hermit crabs in seagrass beds, contribute to their ecological dynamics (Creed 2000). However, environmental changes, such as increased freshwater influx or pollution, pose significant risks to their populations and habitat suitability. These threats underscore the importance of monitoring and conservation efforts to ensure the sustainability of *Cerithium* populations in lagoon ecosystems.

Meanwhile, the presence of *Diadema sp.* may be due to the availability of abundant foods, such as seagrass and algae, in the lagoon as they graze and largely feed on these species (Ogden et al. 1973). Additionally, such abundance could be due to extensive gathering of sea urchins for food consumption which was also observed in the area resulting to the release of pheromones into the water. These pheromones send a chemical message that triggers their conspecifics to eject their sex cells simultaneously to reproduce (Lawrence 2001; Walker et al. 2007).

Oysters (*Ostrea* sp.) were identified as the third most abundant species in the lagoon, with cultivation activities for this species observed near Station 3. Their proliferation in lagoon ecosystems could be shaped by a complex interplay of ecological, environmental, and human factors. Key environmental parameters such as water temperature, salinity, and substrate characteristics significantly influence their abundance. Optimal spawning occurs at temperatures exceeding 14°C, with peak condition indices observed between 11–12°C (Cano et al. 1997). These oysters thrive in brackish environments where fluctuating salinity levels, driven by freshwater inflows, create ideal conditions (Altinsaçli et al. 2018).

The availability of suitable substrates, such as raised topographical formations and shell coverage, further facilitates their gregarious settlement (Smyth et al. 2020).

Biological factors also play a crucial role in their proliferation. The presence of picoplankton, including dinoflagellates and bacteria, provides essential nutrients for growth and reproduction (Cano et al. 1997). High densities of fecund adult oysters enhance natural recruitment and settlement processes (Smyth et al. 2020). However, human activities pose significant challenges to the sustainability of *Ostrea* populations. Unregulated harvesting hampers natural recovery, while additional pressures such as pollution, sedimentation, and interspecies competition further threaten their habitats (Naik and Gowda 2013). These challenges highlight the need for effective management strategies to conserve and sustain *Ostrea* populations in lagoon ecosystems.

Furthermore, the natural occurrence of hermit crabs in specific gastropod shells can be explained by two factors, such as availability of empty shells and their relative abundance in the relevant size (Fransozo et al. 2008). A good number of empty *Cerithium* shells and low number of crab predators, e.g. lobsters and fish, present in the area could explain the abundance of hermit crab (*Paguroidea*) population. Echinoderms are fundamentally good indicators of health and status in marine waters (Llacuna et al. 2016) and the abundance of *Synapta sp*. could be an indication that the lagoon is still in good condition because of its presence in each station.

Diversity of macrobenthic invertebrates

Comparisons of the diversity (H'), species richness (S) and and evenness (J') are presented in Fig. 3. The mean richnness (S), evenness (J') and diversity (H') of macrobenthic invertebrates ranged from 7.33 ± 1.667 to 13.33 ± 1.856, 0.358 ± 0.028 to 0.596 ± 0.094 and 1.187 ± 0.131 to 1.728 ± 0.058 respectively. Results showed that Station 4 had relatively higher species diversity (H' = 1.728 ± 0.058), followed by Station 1 (H'= 1.613 ± 0.105), Station 3 (1.380 ± 0.218) and Station 2 (H' = 1.187 ± 0.131). A relatively higher diversity level observed in Station 4 could be due to the habitat preferences of those six unique species. The substrate types observed in the area were rocks, several broken pieces of shells and coral rubbles which are more suitable for marine gastropods. However, no significant differences on the species diversity were observed between stations. This might be an indication that the lagoon is still in good condition because biodiversity indicates how stable and productive the ecosystem is (Corcoran and Boeing 2012).

Distribution of macrobenthic invertebrates

Figure 4 shows the common and unique species found between stations of the lagoon. Results revealed that there were 10 species common to all stations which include *Cerithium sp*., *Ostrea sp*., *Synapta sp*., *Ophiuroidea*, *Cerripedia*, *Monoplex pilearis*, *Diadema sp*., *Echinometra mathaei*, *Patellidae* and *Paguroidea*. Two unique species (*Perna viridis* and *Bathybiaster loripes*) were found in Station 1 and one species

(*Tripneustes gratilla*) in Station 2. Six species were found in Station 4 which include *Turbinidae*, *Anadara sp*., *Nerita sp*., *Monetaria moneta*, *Monetaria annulus* and *Portunidae*. However, no unique species was found in Station 3.

Assessment of the physico-chemical parameters of the lagoon

The measurements of the four physico-chemical parameters (pH, temperature, total dissolved solids and salinity) in the four sampling stations of the lagoon are presented in Figs. 5–8. Analysis revealed that Station 3 had a significantly lower pH, total dissolved solids and salinity ($p < 0.05$) with the average values of 8.30 ± 0.122, 18.70 ± 1.942 and 24.10 ± 2.727 respectively, compared to other three stations. However, in terms of temperature, only Station 2 and Station 3 showed a significant difference ($p < 0.05$) with the average values of 30.57 ± 0.524 and 32.27 ± 0.067 respectively.

Llacuna et al. (2016) mentioned that human activities and physico-chemical factors such as temperature, salinity, total dissolved solids (TDS) and pH may affect the abundance and distribution of echinoderm and macrobenthic invertebrate species. They further explained that the physico-chemical factors play a role in the diversity and abundance of macrobenthic invertebrates and it can affect the growth rate, metabolic activity and immune response of any aquatic organisms.

There is a large amount of literature on the relationship between environmental parameters and the faunal composition (Wright et al. 1998). However, the relationship between diversity/ richness/ biomass and environmental conditions is less clear. For example, Clarke and Scruton (1997) reported no significant correlation between numbers and diversity of macrobenthic invertebrates and several environmental parameters including pH in 20 areas of Newfoundland, Canada. Effects of temperature on marine waters are still poorly known, particularly in systems where they interact with other environmental variables. Possibly that the major caused to a lower species diversity in Station 2 compared to other stations was not due to a higher temperature but because of the different substrates in the area including garbage as observe in the area during the sampling period. Low diversity can be caused by various anthropogenic activities that affect the intertidal zone like waste disposal from coastal communities (Llacuna et al. 2016). The significant decrease in salinity and total dissolved solids (TDS) in Station 3 could be due to high freshwater inputs coming from the springs and households.

Macroinvertebrate assemblages

Figure 9 and 10 show the nMDS graph and cluster analysis of samples based on abundance data from the four sampling stations in the lagoon. Results of nMDS revealed that no clear segregation (40% similarity) of samples from different stations was observed. Meanwhile, the Cluster analysis also revealed that samples collected from Station 1, Station 2 and Station 4 have close relationship with each other than samples taken from Station 3.

SIMPER analysis revealed that Station 1 and 2 had 69.73% and 70.54% similarity respectively which were largely contributed by *Cerithium sp*., *Diadema sp*. and *Paguroidea*. Station 3 and Station 4 had 64.86% and 76.76% similarity, respectively. High percentage similarity in Station 3 and Station 4 was mainly contributed by *Ostrea sp*., *Cerithium sp*., *Synapta sp*. and *Paguroidea*.

In comparison between stations, results also showed that Station 1 vs Station 2 had a dissimilarity of 31.94% while Station 1 vs Station 3 had 46.53% of dissimilarity Station 2 vs Station 3 had 54.09% of dissimilarity, Station 1 vs Station 4 with 35.09% of dissimilarity, Station 2 vs Station 4 had 35.99%, Station 3 vs Station 4 had 46.47% dissimilarity, respectively. These dissimilarity percentages between stations were largely contributed by *Ostrea sp*., *Cerithium sp*., *Synapta sp*., *Spongia sp*. and *Paguroidea*.

Sabetta et al. (2007) mentioned that the species richness is also strongly affected by external pollution, which can have a major influence on the species–area relationships where relevant anthropogenic pressures occur. Cluster analysis showed the relationship of each station possibly that's one of the reason why station three has a lower relationship compared to other station because of its environmental conditions given that it is shaded by trees and the anthropogenic activities that is present in the said area as observed in the location. While Station 1, 2 and 4 are closely relative to each other because of their environmental condition that are almost the same like physico-chemical parameters such as temperature, salinity, TDS (total dissolved solids) and pH that may affect the abundance and distribution of macrobenthic invertebrate species (Walag and Canencia 2016).

Canonical Correspondence Analysis (CCA) (Fig. 11) revealed that the patterns of macroinvertebrate communities are greatly influenced by the different environmental factors such as salinity, total dissolved solids (TDS), temperature and pH. Benthic macroinvertebrate communities confirmed that permanent salt contamination of macroinvertebrate communities affects the structure of benthic organisms. However, mollusks and crustaceans are capable of surviving in high saline conditions. These results are in accordance with several studies showing that Crustacea are the most salinity tolerant of the major invertebrate taxa groups (Kefford et al. 2003), That indicates that the lower salinity influences the absence of other species in Station 3 compared to other three stations and the role of salinity was defined in terms of total dissolved substance. While temperature has been long recognized as a major factor in the distribution, abundance and richness of aquatic organisms (Vannote et al. 1980). Water temperature is also important for the embryonic development, larval growth, emergence, metabolism and survivorship of aquatic organisms (Haidekker and Hering 2008). Furthermore, other parameters affecting macrobenthic invertebrates' lives include water chemistry, including pH. Most aquatic organisms survive in waters with a pH range of 5.0–9.0.

Therefore, the observed assemblages of macrobenthic invertebrates in the lagoon could be due to tolerable range of environmental factors in all stations of the lagoon.

Conclusion

Macrobenthic invertebrates were investigated in the four sampling stations of an approximately 1.5-km Taguines Lagoon, Mahinog, Camiguin Island, Philippines using transect-quadrat method. Three transects were laid down on each station with 1-m distance interval starting from the coastline. Then, a 0.5-m^2 quadrat was positioned in a left-right side alternately. All macrobenthic invertebrates within the quadrat were immediately identified and counted. Unidentified samples were brought to the laboratory for further identification. Diversity indices [e.g. species richness (S), species evenness (J'), and Shannon-Wiener diversity index (H')] were then measured and statistically analyzed using One-Way ANOVA. Results revealed that there were no significant differences of the species diversity between the four sampling stations.

In terms of relative abundance, *Cerithium sp.* and *Diadema sp.* were found to be the most abundant species in the lagoon. Non-metric multi-dimensional scaling (nMDS) based on square-root transformed abundance data showed no clear segregation between samples from the four sampling stations. Cluster analysis also revealed that there is a close relationship of the samples from Station 1, Station 2 and Station 4. SIMPER analysis also showed that high dissimilarity percentages were observed in most stations and were largely contributed by *Ostrea sp.*, *Cerithium sp.*, *Synapta sp.*, *Spongia sp.* and *Paguroidea*.

The presence and assemblages of macrobenthic invertebrates were found to be influenced by physico-chemical variables such as pH, temperature, salinity, total dissolved solids. However, further study should be conducted to verify the results.

Declarations

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Compliance with Ethical Standards

a) Authors' Contributions

W.C. and M.V. conceptualized the project and developed the materials and methods, conducted the experiment, and processed the samples. W.C., D.F.V. and R.G. managed project administration and supervised the project. W.C. and M.V. analyzed the data and generated the visuals. All authors wrote the manuscript and read, reviewed, and approved the final manuscript.

b) Conflict of Interest

The authors declare that there is no conflict of interest.

c) Statement on the Welfare of Animals

All applicable international, national, and/or institutional guidelines for the care and use of animals were followed.

d) Statement of Human Rights

For this type of study, formal consent is not required.

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Figures

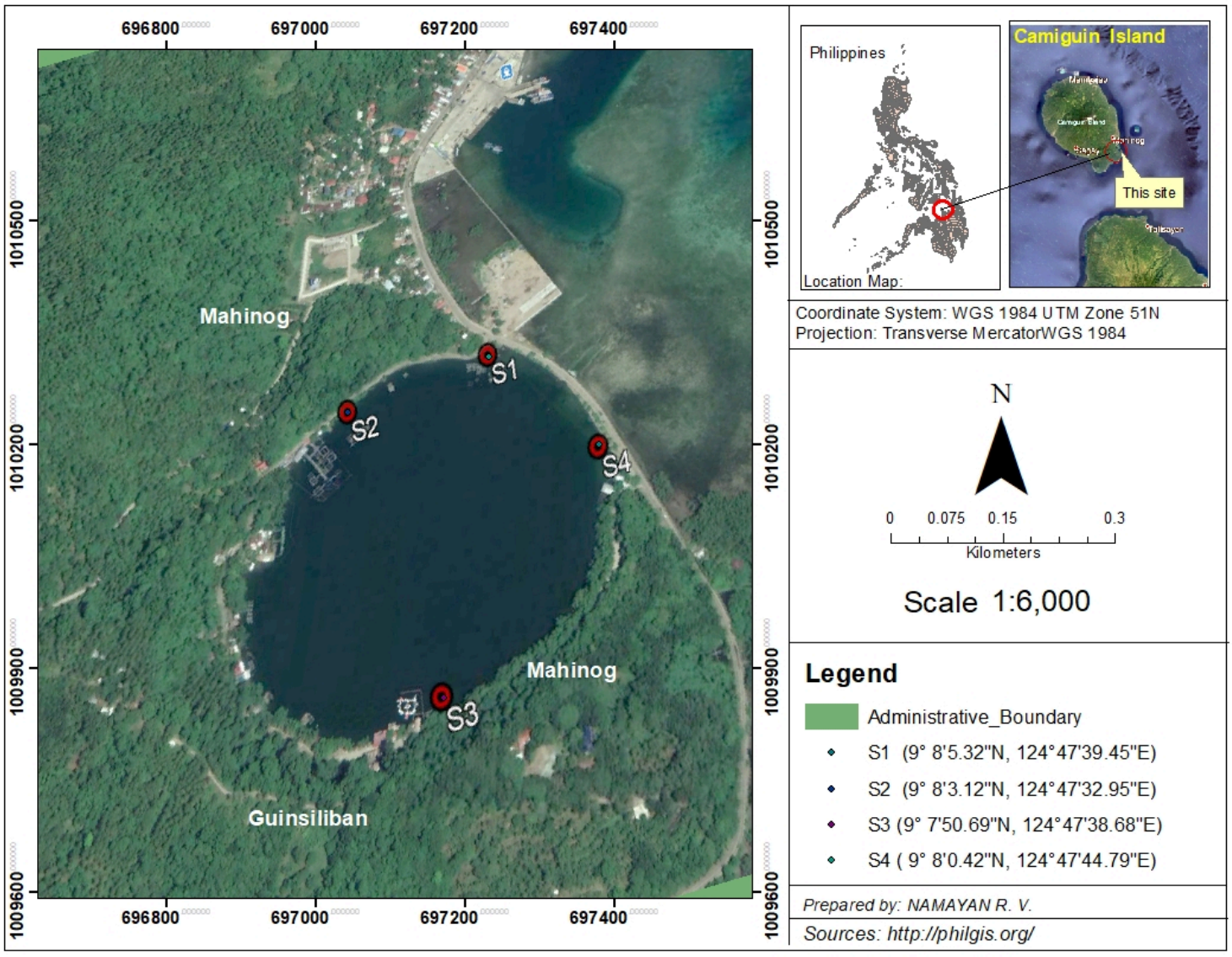


Figure 1

Location map of Taguines Lagoon, Mahinog, Camiguin Island in Mindanao, Philippines.

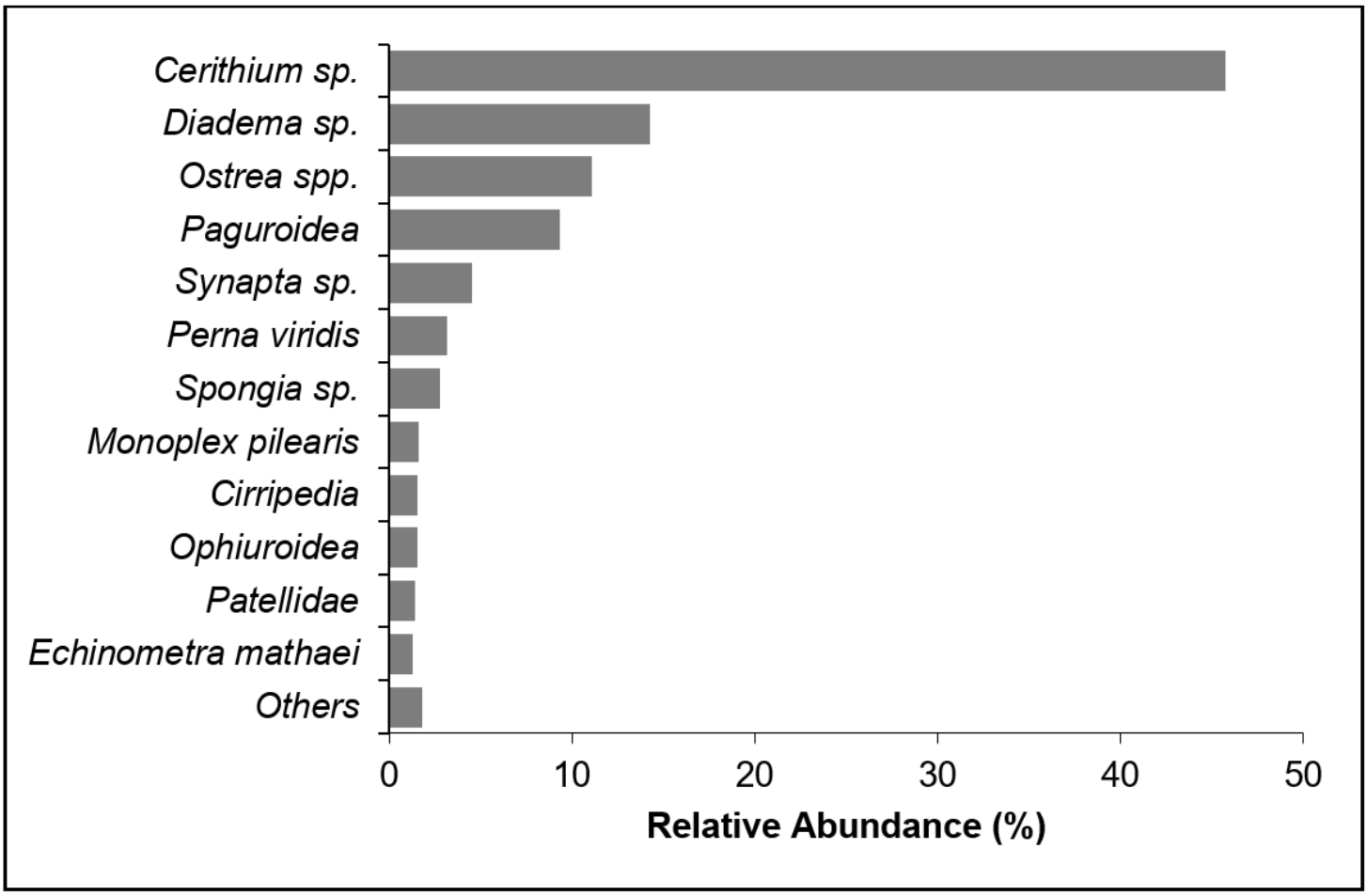


Figure 2

Relative abundance of species present in the four sampling stations established in Taguines Lagoon, Mahinog, Camiguin Island, Philippines

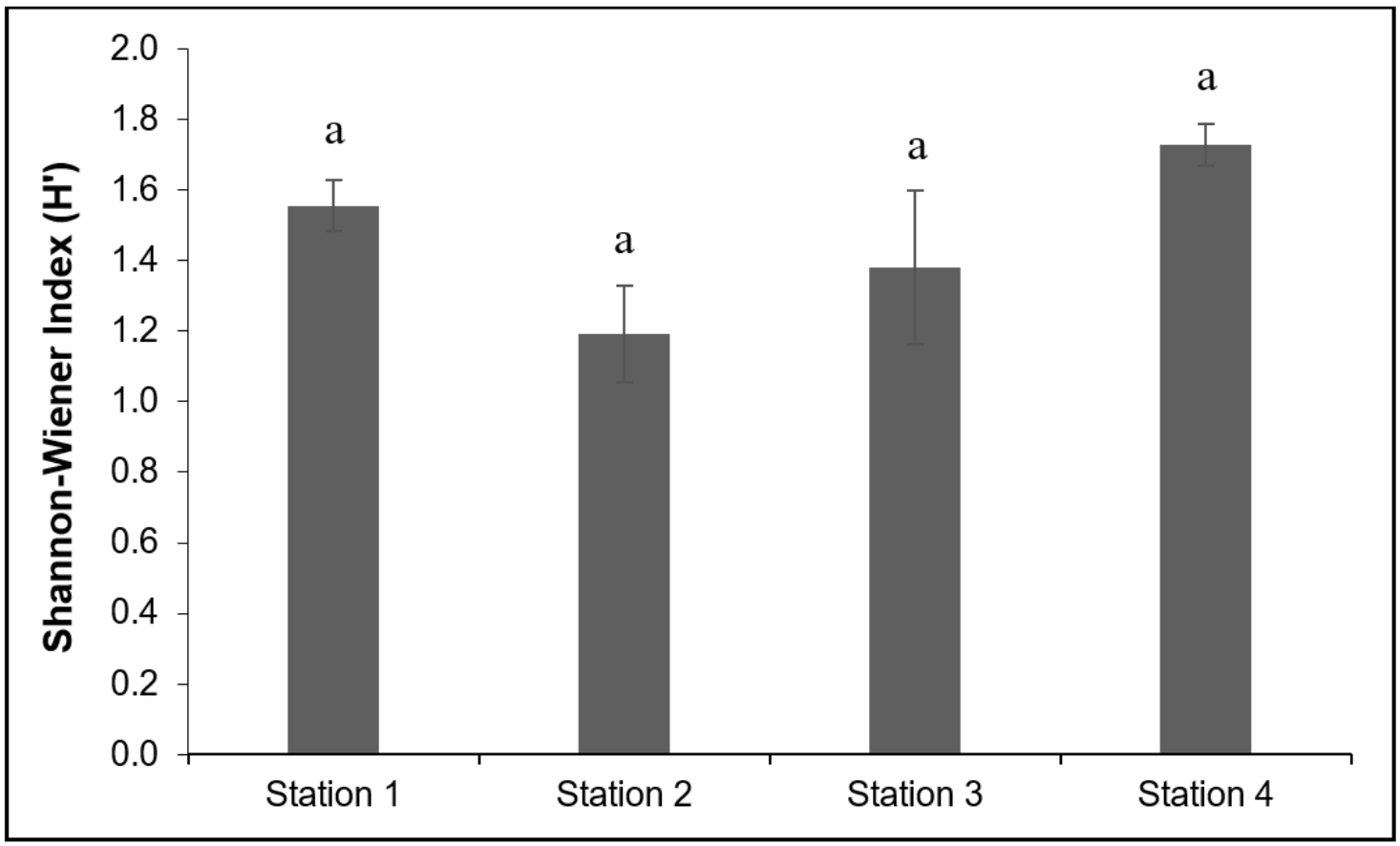


Figure 3

Shannon-Weiner diversity index of the different stations established in Taguines Lagoon, Mahinog, Camiguin Island, Philippines. Values are mean ± S.E. Different letters (a-b; by *ANOVA*) indicates a significant difference ($p < 0.05$) between four sampling stations.

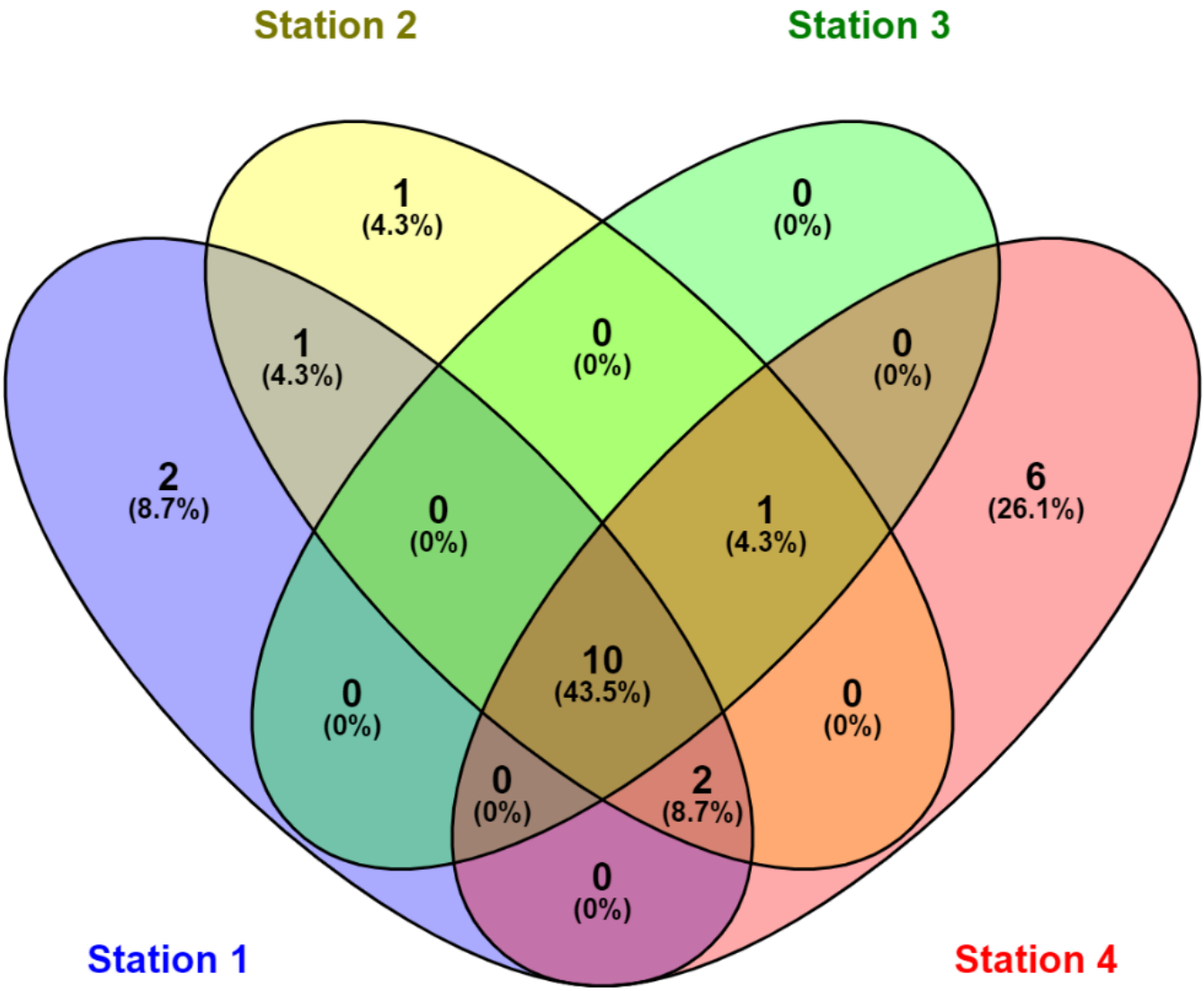


Figure 4

Common and unique species found between stations of Taguines Lagoon, Mahinog, Camiguin Island, Philippines.

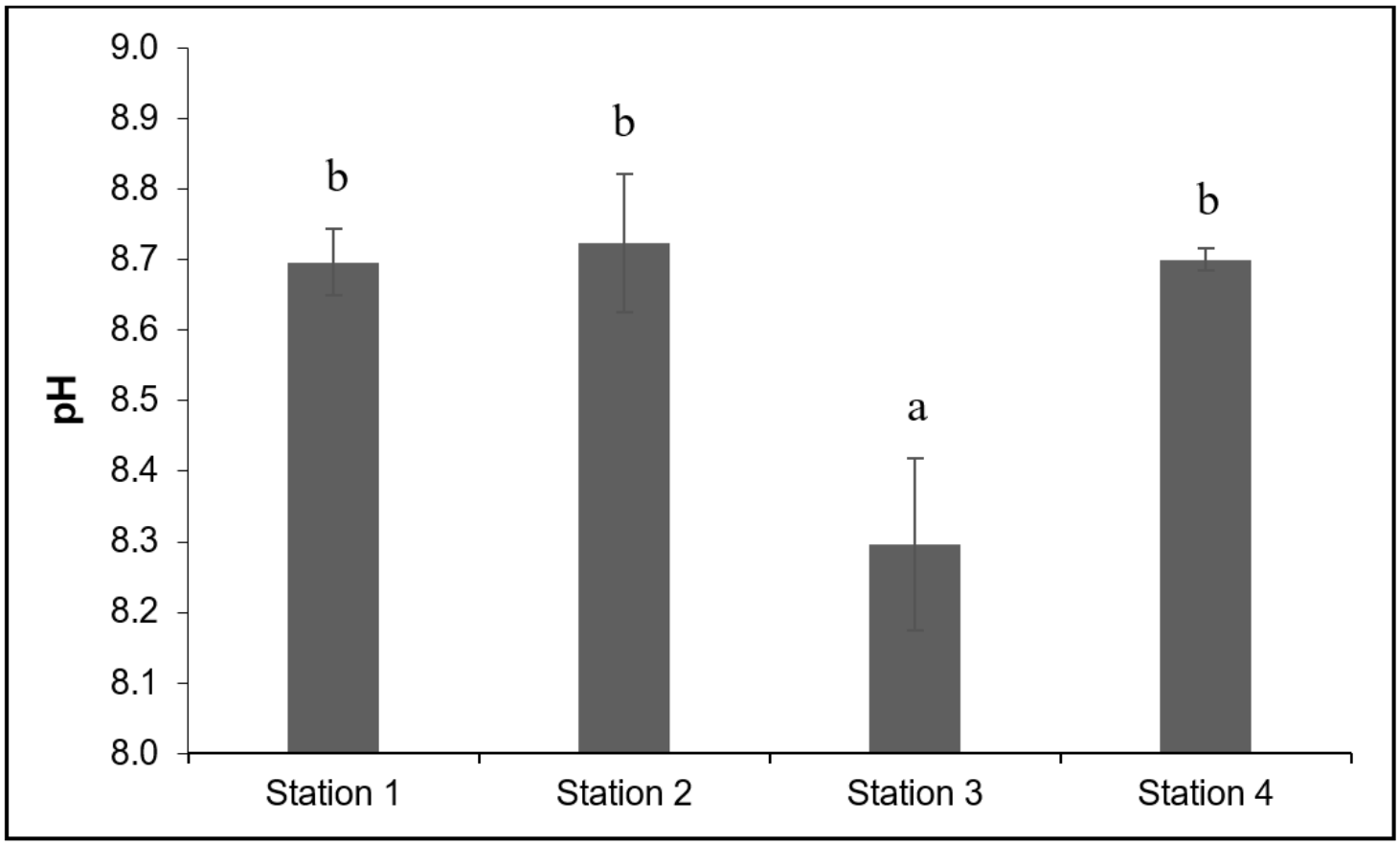


Figure 5

Water pH measurements of the different stations established in Taguines Lagoon, Mahinog, Camiguin Island, Philippines. Values are mean ± S.E. Different letters (a-b; by *ANOVA*) indicate a significant difference ($p < 0.05$) between four sampling stations.

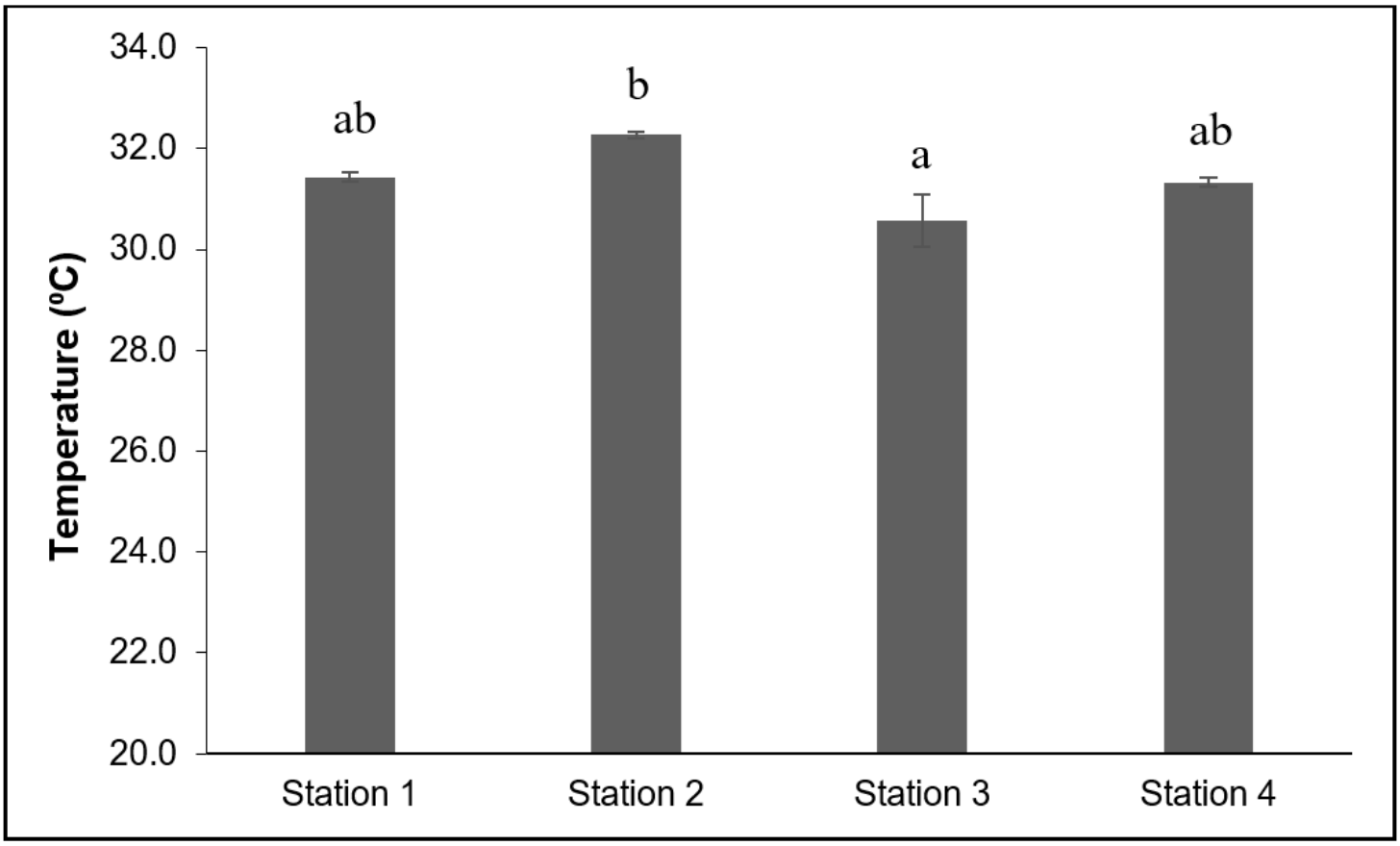


Figure 6

Temperature measurements of the different stations established in Taguines Lagoon, Mahinog, Camiguin Island, Philippines. Values are mean ± S.E. Different letters (a-b; by *ANOVA*) indicate a significant difference ($p < 0.05$) between four sampling stations.

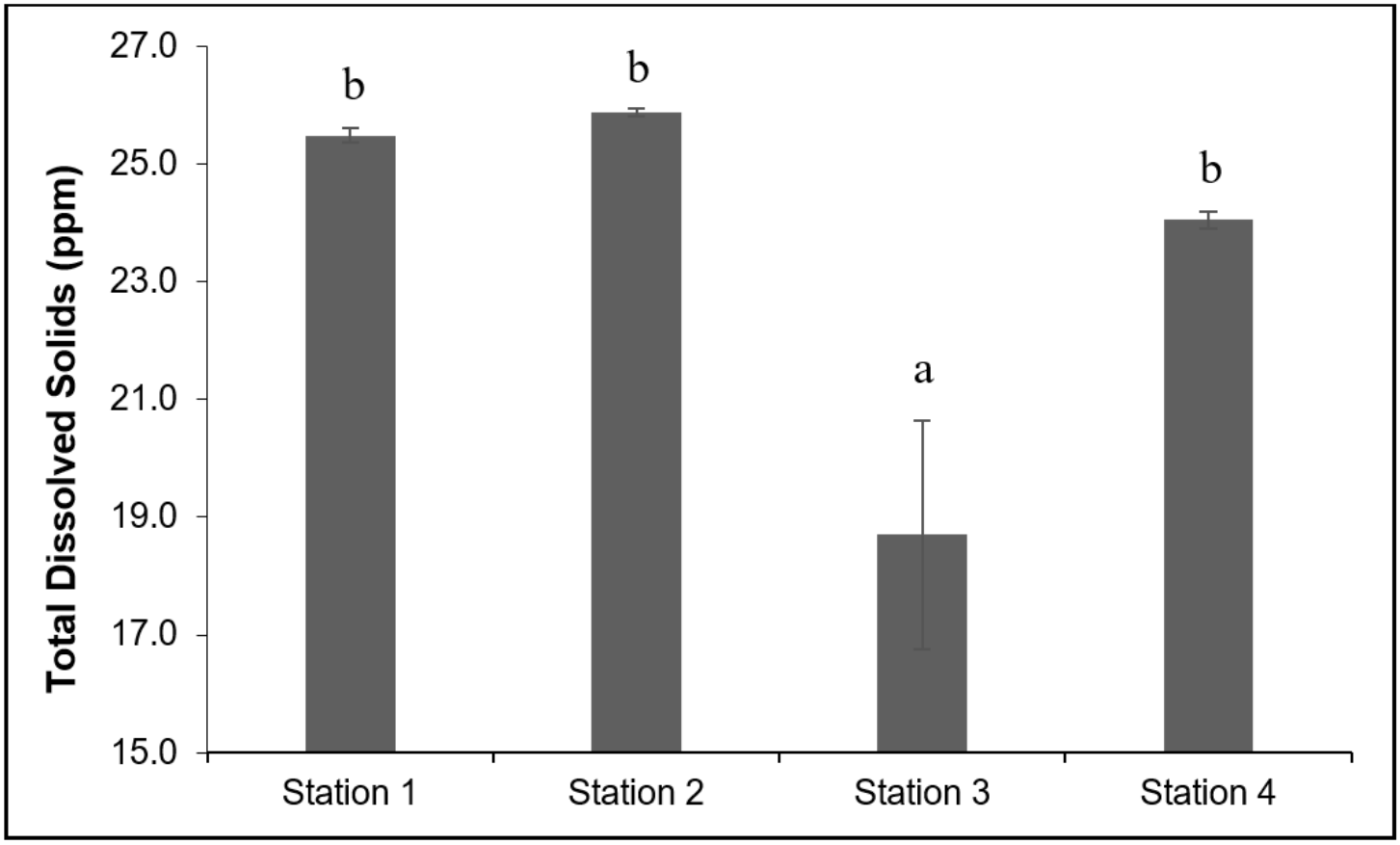


Figure 7

Total dissolved solids (TDS) measurements of the different stations established in Taguines Lagoon, Mahinog, Camiguin Island, Philippines. Values are mean ± S.E. Different letters (a-b; by *ANOVA*) indicate a significant difference ($p < 0.05$) between four sampling stations.

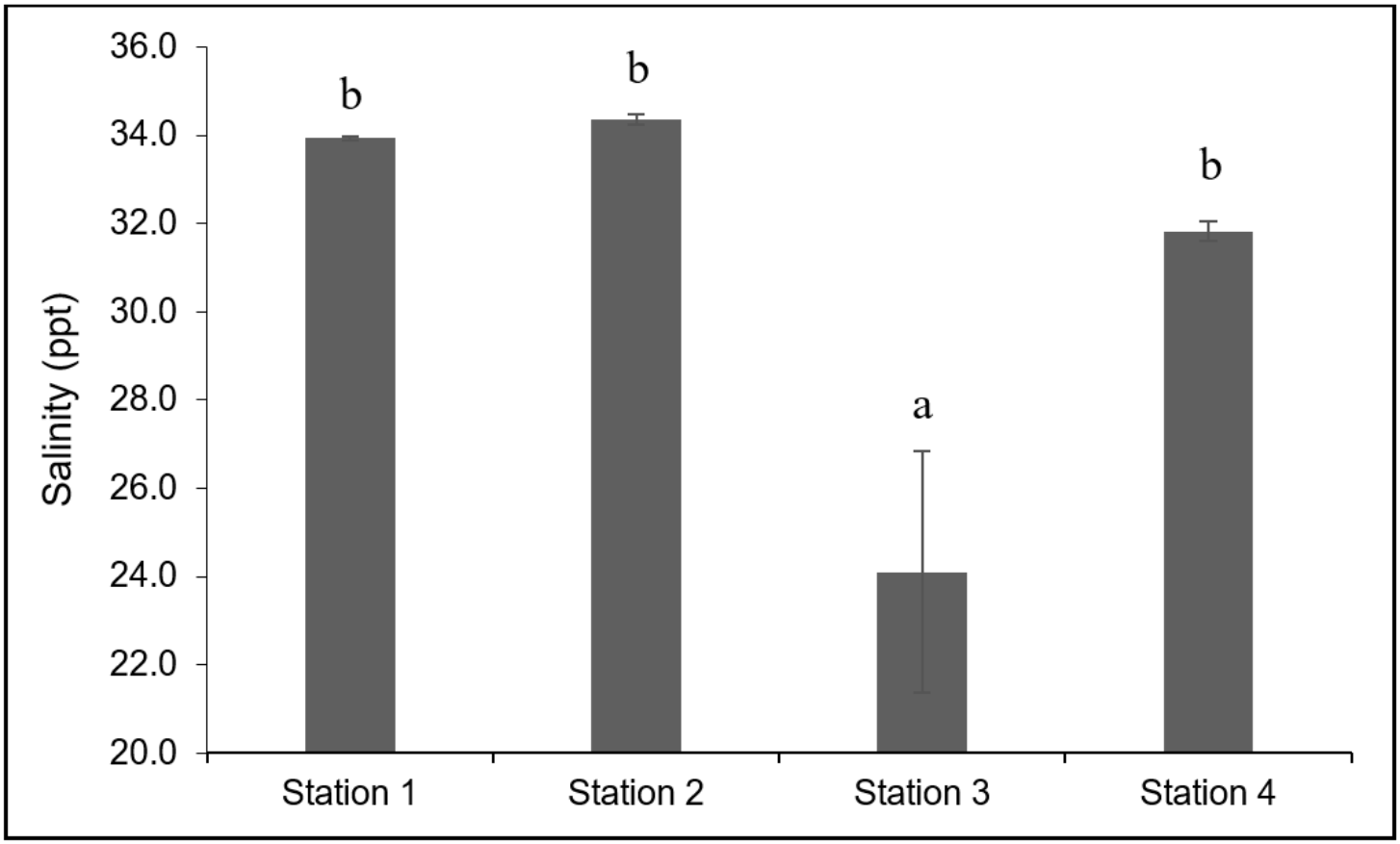


Figure 8

Salinity measurements of the different stations established in Taguines Lagoon, Mahinog, Camiguin Island, Philippines. Values are mean ± S.E. Different letters (a-b; by *ANOVA*) indicate a significant difference ($p < 0.05$) between four sampling stations.

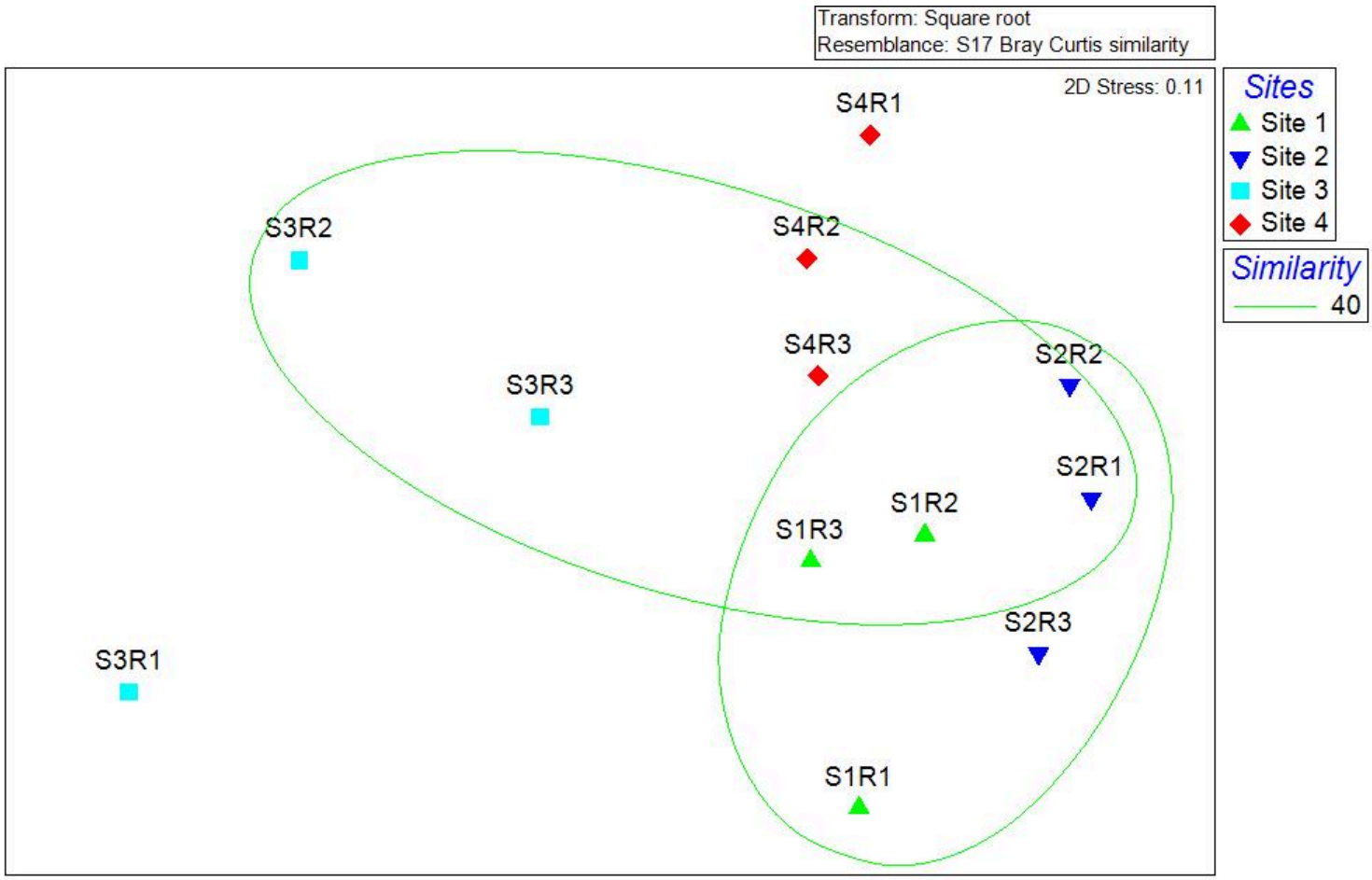


Figure 9

Non-metric multi-dimensional scaling (nMDS) of square-root transformed data of macroinvertebrate abundance data showing the similarities of the samples from the four sampling stations of Taguines Lagoon, Mahinog, Camiguin Island, Philippines.

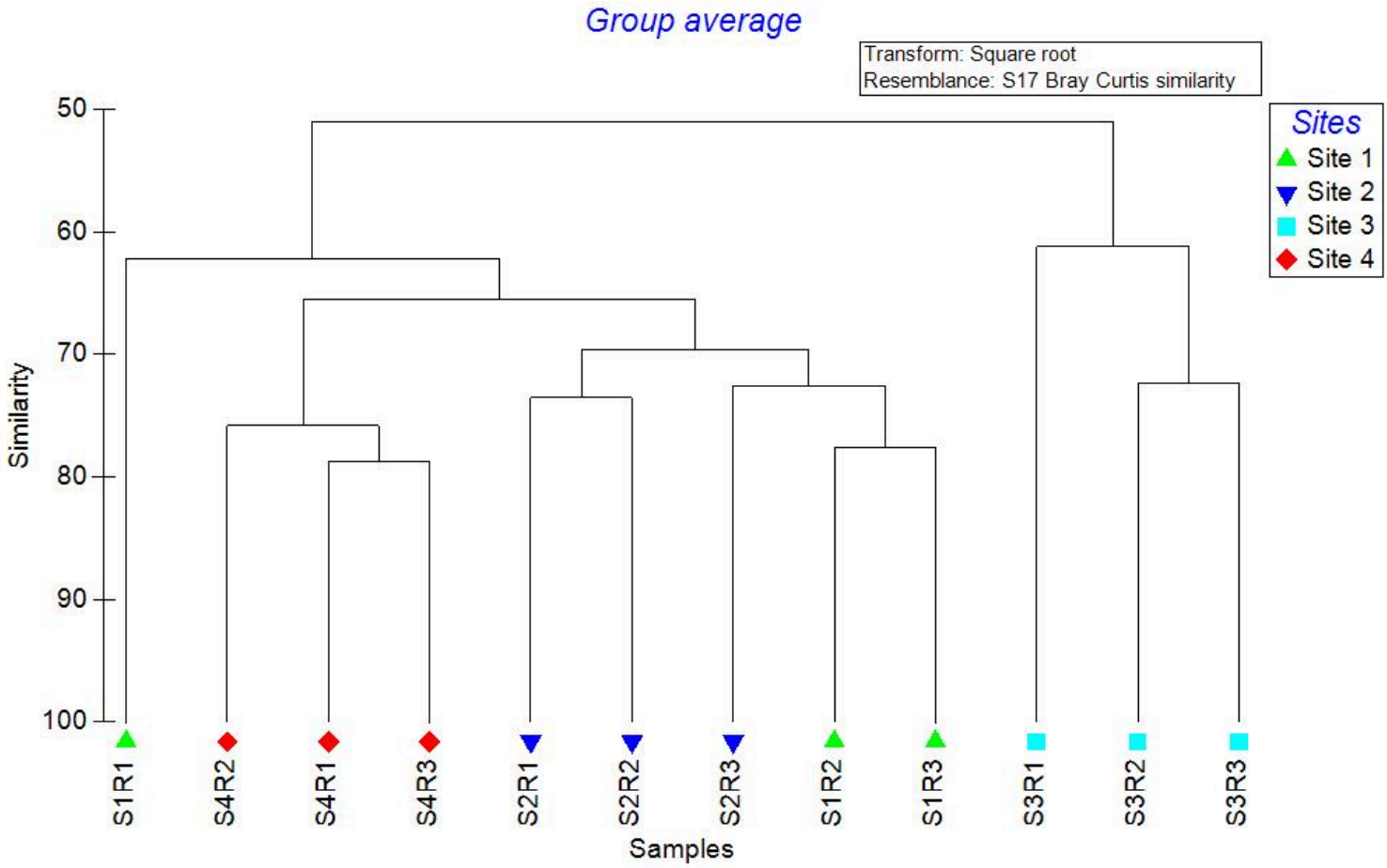
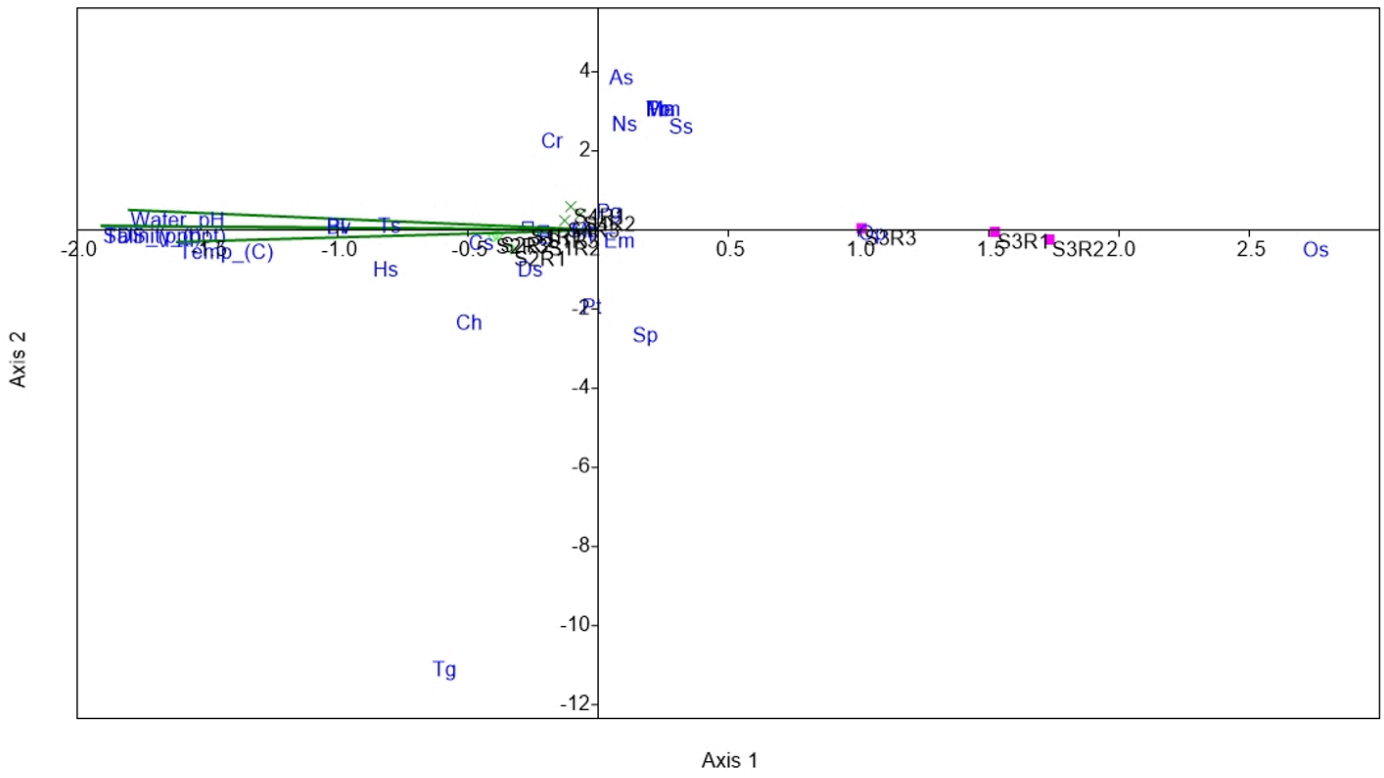


Figure 10

Cluster analysis based on Bray-Curtis similarity resemblance of square-root transformed abundance data showing the similarities of the samples from the four sampling stations of Taguines Lagoon, Mahinog, Camiguin Island, Philippines.



□ = Station 1, ◊ = Station 2, ■ = Station 3, X = Station 4.

Figure 11

Distribution of macrobenthic invertebrates in relation to the physico-chemical parameters. *Legend: : Cr =* Cerithium; *Os = Ostrea; Ss =Synapta; Sp =Spongia; Hs =Holothuria*; *Ch =Chiton; Ns =Nerita*; *Pg =Paguroidea*; *Tg =Tripneustus gratilla; As =Anadara*; *Ts =Thocus*; *Ds = Diadema; Ma = Monotera annulus; Mm = Monotera moneta; Em = Echenometra mathaei; Pv = Perna viridis; Tb = Turbinidae; Op = Ophiuroidea; Mp = Monoplex pilearis; Cp = Cirripedea; Pt = Patellidae; Bl= Bathybiaster loripes; Pr = Portunidae;*