**ACADEMIA JOURNAL OF BIOLOGY** 2025, 47(3): 13–26
DOI: 10.15625/2615-9023/22573

# SEAGRASS ECOSYSTEMS IN PUJADA BAY, DAVAO ORIENTAL, PHILIPPINES: EVALUATING THE IMPACT OF ANTHROPOGENIC PRESSURES ON SPECIES RICHNESS

**Claudine C. Sanchez-Delute[1], Sherwin Edgar B. Atoy[2], Cirilo O. Ybañez Jr.[3,*]**

[1]Department of Environment and Natural Resources - Community Environment and Natural Resources Office, City of Mati, Davao Oriental, Philippines
[2]City Environment and Research Development Department, City of Mati, Davao Oriental, Philippines
[3]Faculty of Agriculture and Life Sciences, Davao Oriental State University, City of Mati, Davao Oriental, Philippines

Received 17 March 2025; accepted 12 September 2025

## ABSTRACT

This study investigates the biodiversity of seagrass ecosystems in Pujada Bay, Davao Oriental, Philippines, with a particular focus on evaluating the impact of anthropogenic pressures on species richness and composition. Seagrass communities from three sites with varying disturbance levels were compared: heavily populated Taganilao, moderately populated Lawigan, and uninhabited Pujada Island. Aerial surveys, transect-quadrat sampling, and environmental measurements (dissolved oxygen (DO), pH, salinity, temperature) were used to assess species distribution, shoot density, and abundance. Results showed that Pujada Island had the highest species richness and a balanced community structure, while Taganilao, impacted by pollution and reclamation, had lower diversity and was dominated by the resilient *Thalassia hemprichii*. Kruskal-Wallis tests confirmed significant differences in abundance, especially between Taganilao and Pujada Island ($p = 0.000273$). Canonical Correspondence Analysis highlighted temperature and DO as key drivers of species distribution. The study underscores the urgent need for conservation measures to mitigate human impacts and protect seagrass ecosystems in Pujada Bay.

**Keywords:** Seagrass biodiversity, anthropogenic pressures, Pujada Bay, species richness, marine conservation.

*Citation*: Claudine C. Sanchez-Delute, Sherwin Edgar B. Atoy, Cirilo O. Ybañez Jr., 2025. Seagrass ecosystems in Pujada bay, Davao Oriental, Philippines: evaluating the impact of anthropogenic pressures on species richness. *Academia Journal of Biology*, 47(3): 13–26. https://doi.org/10.15625/2615-9023/22573

[*]*Corresponding author email*: cirilo.ybanezjr@dorsu.edu.ph

## INTRODUCTION

Seagrasses are the only flowering plants fully adapted to marine environments (Ma et al., 2024), playing a crucial role in the health and functionality of coastal ecosystems (Unsworth et al., 2022). These angiosperms thrive in shallow, nutrient-rich, and slightly reducing sediments in coastal waters (Qin et al., 2021), forming extensive meadows that support various ecological functions (Nordlund et al., 2024). Particularly in tropical and subtropical regions, seagrass meadows offer critical habitats for a wide variety of marine organisms, ranging from ecologically significant meiofauna (Ybañez Jr, 2024), copepods (Pislan & Ybañez Jr, 2024), and foraminifera (Felix et al., 2022), to commercially important fish species (Ybañez Jr & Gonzales, 2023), and endangered fauna such as dugongs (*Dugong dugon*) (Lanyon et al., 2024) and sea turtles (Tapilatu et al., 2022). These ecosystems are vital for providing food and shelter and preserving the coastal zone's structural integrity (Moreira-Saporiti et al., 2023). Seagrasses deliver essential ecosystem services, including sediment stabilization, water filtration, and carbon sequestration, contributing significantly to climate change mitigation (Lima et al., 2023). Despite their ecological and climate-related importance, seagrass meadows are increasingly threatened by human activities, including coastal development, pollution, and unsustainable fishing practices (Amone-Mabuto et al., 2023), all of which jeopardize their resilience and undermine the critical ecosystem services they provide.

In the Philippines, seagrasses are distributed across various coastal ecosystems, including shallow bays, lagoons, and coral reef-associated habitats. The country is home to 18 species of seagrasses (Arriesgado et al., 2024), which include *Enhalus acoroides*, *Cymodocea rotundata*, *Oceana serrulata*, *Halodule pinifolia*, *Halodule uninervis*, *Thalassia hemprichii*, *Thalassodendron ciliatum*, *Syringodium isoetifolium*, *Halophila ovalis*, *Halophila decipiens*, *Halophila beccarii*, *Halophila minor*, *Halophila gaudichaudii*, *Halophila spinulosa*, *Halophila ovata*, *Halophila* sp. 1, and *Halophila* sp. 2. These species contribute significantly to marine biodiversity, providing critical habitats and supporting the sustainability of local fisheries. A notable study by Angsinco-Jimene et al. (2003) was conducted in Pujada Bay, identifying nine seagrass species, including *C. rotundata*, *O. serrulata*, *E. acoroides*, *H. pinifolia*, *H. uninervis*, *H. minor*, *H. ovalis*, *S. isoetifolium* and *T. hemprichii*. However, this research primarily focused on species occurrence and did not evaluate the diversity, health, or anthropogenic impacts on seagrass ecosystems within the bay. Since this study in 2003, no further research has been conducted to assess the current state of seagrass ecosystems in Pujada Bay, leaving a significant gap in understanding how these ecosystems have been affected by human-induced pressures.

The present study aims to fill this gap by investigating the current status of seagrass biodiversity in Pujada Bay, focusing on the impact of anthropogenic pressures on species richness and composition. This research will compare seagrass ecosystems at three distinct sites within the bay: a heavily populated area (Taganilao), a moderately populated area (Lawigan), and an uninhabited area (Pujada Island). By assessing seagrass diversity across these sites, the study will provide valuable insights into how varying levels of human activity affect the health and biodiversity of seagrass meadows. The findings will contribute to a more comprehensive understanding of the relationship between human activities and seagrass ecosystems, helping to guide conservation efforts in Pujada Bay and similar coastal areas.

## MATERIALS AND METHODS

### Study area

This study was conducted at selected locations within Pujada Bay, Davao Oriental, Philippines, in January 2017 (Fig. 1, Table 1). Three distinct sites were chosen to represent varying levels of anthropogenic influence and their potential impact on seagrass ecosystems: Station 1 (heavily populated area, Taganilao), Station 2 (moderately populated area, Lawigan), and Station 3 (uninhabited area, Pujada Island) (Fig. 2). These sites were strategically selected to provide a range of environmental conditions influenced by human activity, enabling a comprehensive assessment of seagrass ecosystem health and diversity under different levels of disturbance.

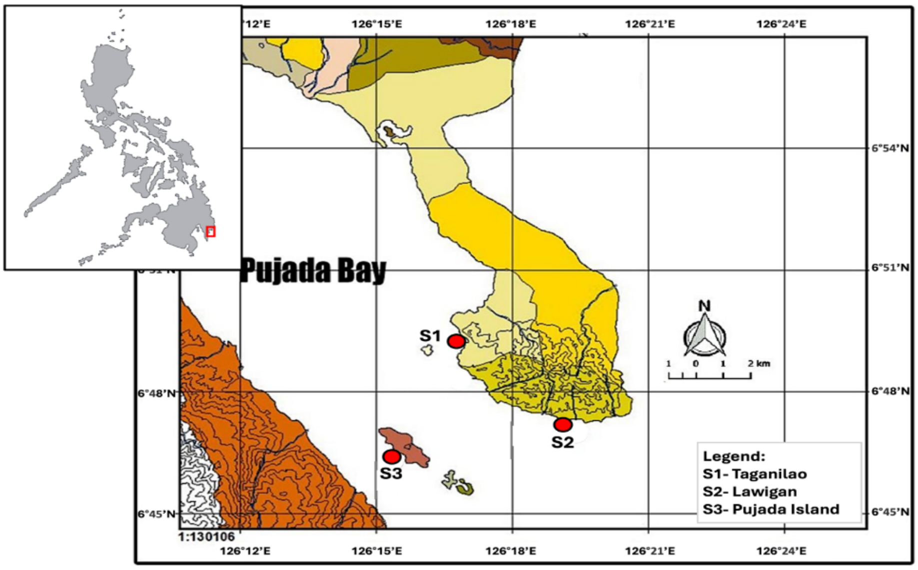


*Figure 1.* Map showing the three research locations within Pujada Bay, Davao Oriental, Philippines

*Table 1.* Geographic coordinates for each study station

| Station | Location | Coordinate |
|---|---|---|
| 1 | Taganilao | 6°83'10''N, 126°28'95''E |
| 2 | Lawigan | 6°79'90''N, 126°33'25''E |
| 3 | Pujada Island | 6°78'65''N, 126°26'32''E |

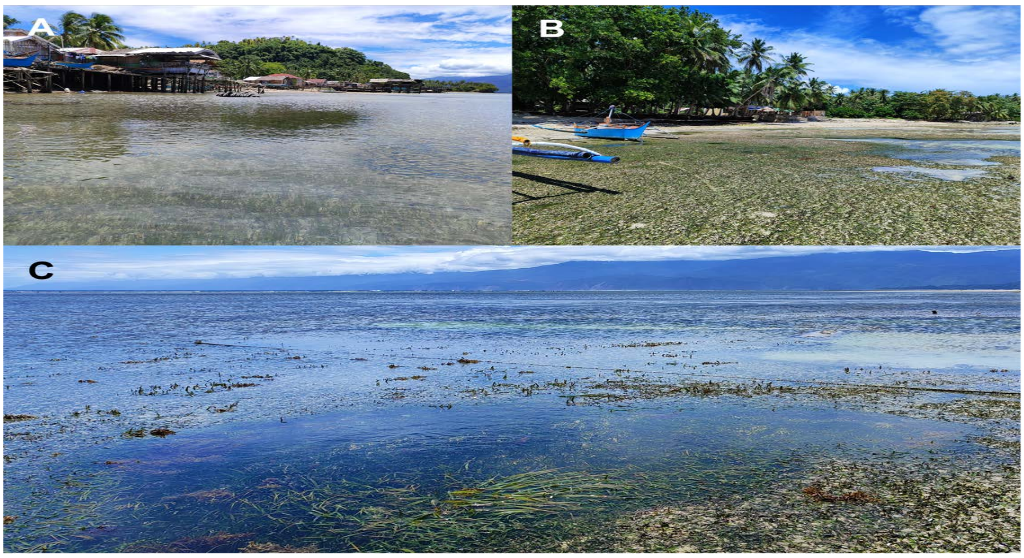


*Figure 2.* The study sites in Pujada Bay: A. Taganilao (heavily populated area), B. Lawigan (moderately populated area), and C. Pujada Island (uninhabited area)

Station 1 (Taganilao): Situated in a high-density residential area, Station 1 is characterized by significant coastal development and a range of human activities, including fishing, tourism, agriculture, and fish ponds. This site is subject to substantial anthropogenic pressures, such as pollution, sedimentation from agricultural runoff, and land reclamation, adversely affecting seagrass meadows. Additionally, the fish ponds contribute to increased sedimentation and nutrient loading, further impacting the ecological integrity of the seagrass ecosystem. Consequently, Station 1 is expected to exhibit higher levels of disturbance, which may influence species diversity and overall ecosystem structure.

Station 2 (Lawigan): Situated in a moderately populated area, Station 2 is less urbanized than Station 1 but still experiences moderate levels of human activity, including small-scale agriculture and fishing. The intensity of anthropogenic pressures here is comparatively lower, offering a more balanced environment to assess the effects of moderate human influence on seagrass meadows.

Station 3 (Pujada Island): Station 3 is located on an uninhabited island with minimal human presence. The area is less impacted by coastal development, pollution, and other anthropogenic disturbances, making it ideal for evaluating the natural, undisturbed state of seagrass ecosystems. This station serves as a baseline for understanding the conditions of relatively pristine seagrass habitats in Pujada Bay.

**Data collection and field survey**

To assess the distribution and extent of seagrass meadows, an aerial reconnaissance was conducted using a GoPro-equipped aircraft to capture high-resolution aerial photographs. These images provided valuable insights into seagrass beds' spatial distribution and boundaries, offering a broad overview of the study area. The aerial photography facilitated precise mapping and location identification for subsequent field surveys.

Field surveys were performed during the lowest low tide to ensure optimal access to the seagrass meadows and enhance the seagrass beds' visibility. Conducting the surveys at this specific tidal stage minimized interference from tidal fluctuations, ensuring consistent environmental conditions across all sampling sites. The transect-quadrat method was employed to quantify seagrass species composition and shoot density. Based on the results from the aerial reconnaissance, three survey stations were selected, representing the seagrass ecosystems within the study area. At each station, three 50-meter transects were randomly oriented across the seagrass meadows. Ten 50 × 50 cm quadrats were randomly placed along each transect to sample the seagrass community. An underwater GoPro camera was used to document the quadrat samples to ensure accurate species identification and minimize observer bias. Additionally, expert assistance was sought to verify the species identified in the field, ensuring the data's reliability and accuracy.

**Environmental parameters**

Each sampling station recorded key environmental parameters influencing seagrass growth and health. These parameters included dissolved oxygen (DO), pH, salinity, and temperature. Salinity was measured with a handheld refractometer, while pH was determined using a portable pH meter to assess the water's acidity or alkalinity. Temperature and DO levels were recorded using a DO meter. All environmental parameters were measured in triplicate at each station to ensure data consistency and reliability.

**Data analysis**

The collected data were analyzed using standard methods for ecological studies. Population shoot density was calculated by counting the number of seagrass shoots of each species within the quadrats. The population shoot density was calculated as: Population Shoot Density = Number of Shoots/Area Sampled.

Abundance was determined by calculating the shoot count for each species, dividing the number of shoots of each species by the total number of shoots within each station, and multiplying by 100 to express the relative abundance as a percentage.

A normality test was conducted to assess the distribution of data. Since the seagrass data were non-parametric, Kruskal-Wallis analysis was performed, followed by post-hoc analysis to determine the significant differences between groups.

The diversity and community structure of seagrass species were assessed using several ecological indices, including the Shannon-Wiener Diversity Index (H'), Simpson's Dominance Index (1-D), Dominance (D), and Evenness (J') (Magapan & Ybañez Jr, 2025). Additionally, Cluster Analysis was performed using the Bray-Curtis similarity index to assess the similarities between sites (Suriya et al., 2022). Canonical Correspondence Analysis (CCA) was employed to investigate the relationships between seagrass species composition and environmental variables (Kinamot, 2024).

All statistical analyses were conducted using Paleontological Statistics (PAST) software, version 4.15, which enabled robust multivariate analysis and provided a detailed understanding of the ecological dynamics of the seagrass ecosystems in Pujada Bay.

## RESULTS AND DISCUSSION

### Seagrass species distribution

The distribution of seagrass species across Taganilao, Lawigan, and Pujada Island in Pujada Bay showed distinct patterns influenced by varying levels of human activity and environmental conditions. *C. rotundata*, *H. ovalis*, *S. isoetifolium*, and *T. hemprichii* were present at all three sites, but *E. acoroides* occurred only at Pujada Island (Table 2). According to Rahayu et al. (2023), seagrass diversity is generally higher in areas with minimal human disturbance, which aligns with the high diversity observed at Pujada Island. Taganilao, heavily impacted by agricultural runoff, sedimentation, and coastal development, exhibited reduced biodiversity and absence of *E. acoroides*, which is sensitive to increased nutrient loads and turbidity. Similar findings were reported by Reyes et al. (2022) in other disturbed Philippine coastal areas. Lawigan, with moderate human activities such as small-scale farming and fishing, maintained greater diversity than Taganilao but still lacked *E. acoroides*. While moderate impacts allowed more species to persist, certain sensitive taxa remained absent. In contrast, Pujada Island, the least disturbed site, supported all recorded species, underscoring the importance of minimal anthropogenic interference in maintaining seagrass health.

Since 2003, Taganilao and Lawigan have likely experienced population growth, agricultural expansion, and intensified coastal development, leading to higher pollution, sedimentation, and nutrient enrichment. These pressures have contributed to declines in biodiversity and abundance, especially for disturbance-sensitive species. Natural stressors, such as storm events and climate change, also exacerbate habitat degradation through physical damage, sediment resuspension, and shifts in temperature, salinity, and sea level.

*Table 2.* List of Seagrass species present at three selected sites in Pujada Bay

| Seagrass species | Taganilao | Lawigan | Pujada Island |
|---|---|---|---|
| *Cymodocea rotundata* Ascherson & Schweinfurth, 1870 | + | + | + |
| *Enhalus acoroides* (Linnaeus f.) Royle, 1839 | - | - | + |
| *Halophila ovalis* (R.Brown) J.D. Hooker, 1858 | + | + | + |
| *Syringodium isoetifolium* (Ascherson) Dandy, 1939 | + | + | + |
| *Thalassia hemprichii* (Ehrenberg) Ascherson, 1871 | + | + | + |

*Note:* "+": presence; "-": absence.

**Seagrass shoot density and abundance**

The shoot density data for seagrass species across the three stations in Pujada Bay reveal significant differences in abundance among species and sites (Fig. 3). Overall, shoot densities were highest at Pujada Island, followed by Lawigan, with Taganilao generally exhibiting the lowest densities.

At Taganilao, *T. hemprichii* exhibited the highest shoot density at 1256 shoots/m$^2$, followed by *S. isoetifolium* (204 shoots/m$^2$) and *H. ovalis* (172 shoots/m$^2$). *C. rotundata* had a very low shoot density of only 16 shoots/m$^2$, and *E. acoroides* was absent. At Lawigan, *S. isoetifolium* had the highest density with 1060 shoots/m$^2$, followed by *T. hemprichii* at 947 shoots/m$^2$, *C. rotundata* with 156 shoots/m$^2$, *H. ovalis* at 124 shoots/m$^2$, and *E. acoroides* was also absent. At Pujada Island, the shoot densities were considerably higher for most species. *S. isoetifolium* had the highest density (2187 shoots/m$^2$), followed by *T. hemprichii* (1687 shoots/m$^2$), *C. rotundata* (1626 shoots/m$^2$), *H. ovalis* (133 shoots/m$^2$), and *E. acoroides* (9 shoots/m$^2$).

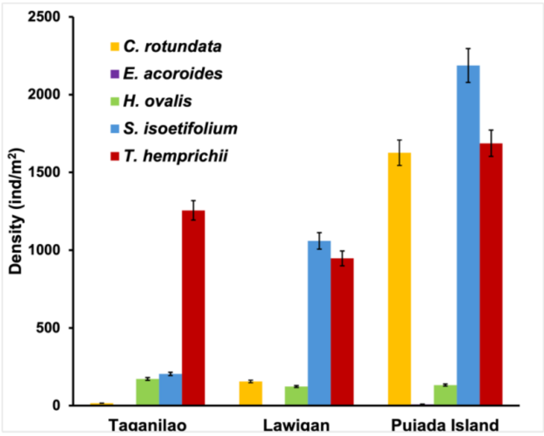


*Figure 3.* The seagrass species density in each site in Pujada Bay

These density patterns align with Zalsos et al. (2021), who reported that less disturbed areas generally support higher seagrass densities and biodiversity, a trend clearly reflected in Pujada Bay. The low densities at Taganilao can be attributed to high anthropogenic pressures such as agricultural runoff, sedimentation, and coastal development, which degrade water quality and reduce light penetration. The absence of *E. acoroides*, a species sensitive to turbidity and nutrient enrichment, further indicates poor habitat conditions, while the dominance of *T. hemprichii* highlights its tolerance for disturbed environments, as also noted by Nugraha et al. (2017) and Shen et al. (2022). In contrast, Lawigan's moderate disturbance level allowed for higher densities and a more varied community than Taganilao, consistent with Soissons et al. (2016), who observed that moderately impacted seagrass beds can still sustain diverse assemblages. However, the continued absence of *E. acoroides* suggests that even moderate stressors can exclude highly sensitive species. The relatively high abundance of *S. isoetifolium* at Lawigan supports Olive et al. (2022), who identified its adaptability to environments with moderate nutrient and sediment inputs. At the other end of the disturbance gradient, Pujada Island's pristine conditions with minimal pollution, low sedimentation, and clear waters supported the highest densities across most species, including both disturbance-tolerant taxa and sensitive species such as *E. acoroides*. This pattern concurs with Swadling et al. (2023), who emphasized that even resilient species perform best under optimal conditions, resulting in both high diversity and density.

Relative abundance patterns (Fig. 4) further illustrate the effects of disturbance, with Taganilao showing clear dominance by *T. hemprichii* (76%), followed by much smaller proportions of *S. isoetifolium* (12%), *H. ovalis* (11%), and *C. rotundata* (1%), and complete absence of *E. acoroides*, indicating reduced community balance driven by high human impact. Lawigan exhibited a more even distribution, with *S. isoetifolium* (46%) and *T. hemprichii* (41%) as co-dominants, along with *C. rotundata* (7%) and *H. ovalis* (6%), yet still lacked *E. acoroides*, reflecting ongoing constraints for sensitive species even under moderate disturbance. In contrast, Pujada Island displayed the most balanced community, with *S. isoetifolium* (39%), *T. hemprichii* (30%), and *C. rotundata* (29%) complemented by small shares of *H. ovalis* (2%) and *E. acoroides* (0.01%), indicative of stable ecological conditions where both resilient and sensitive taxa coexist. Overall relative abundance was lowest at Taganilao (17%), intermediate at Lawigan (24%), and highest at Pujada Island (56%), a pattern consistent with Hastings et al. (2020) and Tang & Hadibarata (2022), underscoring that intense disturbance narrows diversity and favors a few tolerant species, whereas undisturbed habitats maintain balanced, species-rich communities essential for sustaining seagrass ecosystem health in Pujada Bay.

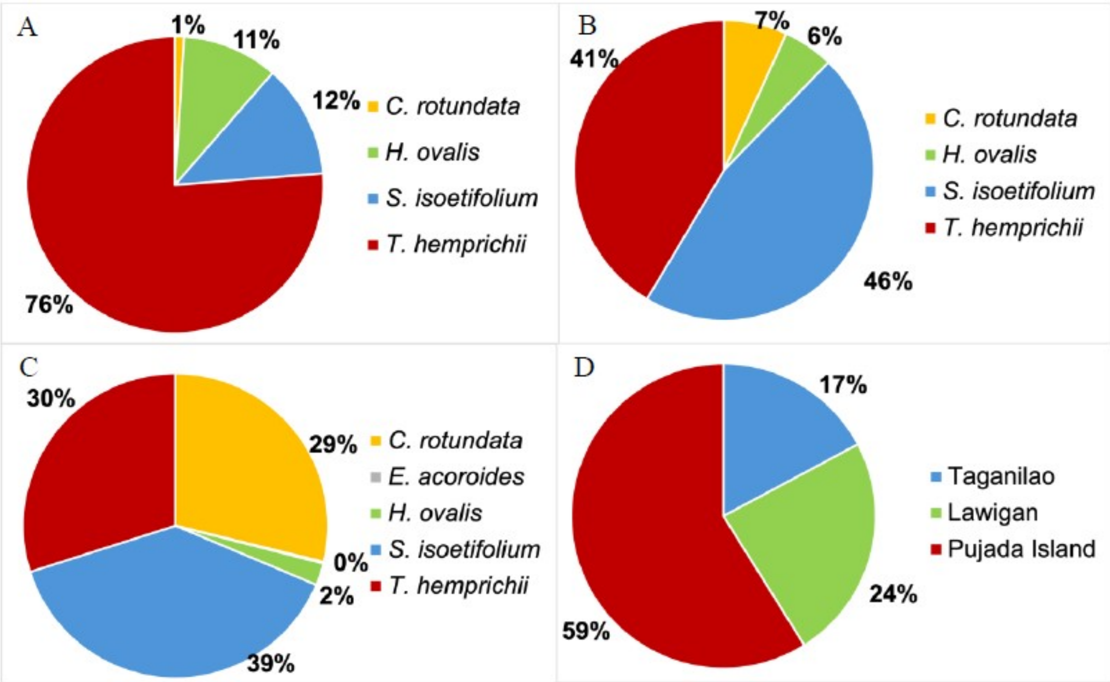


*Figure 4.* Seagrass coverage at each study site: A. Taganilao, B. Lawigan, C. Pujada Island, and D. Total coverage at each station

**Seagrass species diversity**

Diversity indices varied across the three Pujada Bay stations (Table 3), reflecting differences in disturbance levels. Taganilao had a species richness (S) of 4, with low Shannon diversity (H' = 0.75), low Simpson diversity (1 – D = 0.39), and a relatively high dominance index (D = 0.61), indicating a community dominated by few species. Evenness (J' = 0.53) suggests uneven species distribution, consistent with high anthropogenic pressures such as pollution, sedimentation, and coastal development. These conditions likely limit species capable of surviving, favoring disturbance-tolerant taxa like *T. hemprichii*, as also noted by Atencio et al. (2024).

Lawigan also had a richness of 4 but higher diversity (H' = 1.06) and evenness (J' = 0.73), with a lower dominance index (D = 0.39). This indicates a more balanced community structure under moderate human impacts from small-scale agriculture and fishing. These results align with Liu et al. (2025), who found that moderate disturbances can still support diverse seagrass assemblages if impacts are not severe.

Pujada Island, the least disturbed site, showed the highest richness (S = 5), greatest Shannon diversity (H' = 1.19), highest

Simpson diversity (1 – D = 0.68), and lowest dominance (D = 0.32), with moderately high evenness (J' = 0.65). These values indicate a stable, balanced community where both disturbance-tolerant and sensitive species thrive. This pattern matches findings by Hordijk et al. (2023) and Wang et al. (2021), who emphasized that pristine conditions promote maximum diversity, evenness, and ecological stability, underscoring the importance of conserving such undisturbed habitats.

*Table 3.* Diversity indices of seagrasses in Pujada Bay

| Sites | Species Richness (S) | Shannon Diversity Index (H') | Simpson Diversity Index (1 – D) | Dominance (D) | Evenness (J') |
|---|---|---|---|---|---|
| Taganilao | 4 | 0.75 | 0.39 | 0.61 | 0.53 |
| Lawigan | 4 | 1.06 | 0.61 | 0.39 | 0.73 |
| Pujada Island | 5 | 1.19 | 0.68 | 0.32 | 0.65 |

**Kruskal-Wallis H test and post-hoc pairwise comparisons**

The Kruskal-Wallis H test revealed significant differences in seagrass abundance across the three sites in Pujada Bay (H = 12.94, p = 0.001294) (Table 4). Post-hoc Tukey comparisons showed no significant difference between Taganilao and Lawigan (mean difference = -42.12, p = 0.105100), indicating that despite Taganilao's higher disturbance from pollution, sedimentation, and coastal development, its abundance levels were comparable to the moderately impacted Lawigan. This suggests that certain species present in both sites may be resilient to moderate levels of disturbance, consistent with Connolly et al. (2018), who reported that seagrass in moderately impacted areas can maintain relatively stable abundance depending on species tolerance. In contrast, Taganilao showed a highly significant difference in abundance compared to Pujada Island (mean difference = -108.47, p = 0.000273), highlighting the stark contrast between heavily disturbed and pristine conditions. The much lower abundance at Taganilao is likely a result of cumulative anthropogenic pressures that hinder seagrass growth and establishment, aligning with McMahon et al. (2022), who found that intense human disturbance greatly reduces seagrass abundance. The Lawigan versus Pujada Island comparison also showed a significant difference (mean difference = -66.35, p = 0.043490), although less pronounced than the Taganilao-Pujada Island contrast. This suggests that even moderate activities such as small-scale agriculture and fishing can still impact seagrass health, as supported by McCloskey & Unsworth (2015), who observed that cumulative moderate disturbances can limit optimal growth conditions. Pujada Island's minimal disturbance supports the highest abundance among the three sites, emphasizing the importance of protecting low-impact habitats to sustain healthy and productive seagrass meadows in Pujada Bay.

*Table 4.* Results of the Kruskal-Wallis H test and post-hoc pairwise comparisons for seagrass abundance across three sites in Pujada Bay

| Comparison | Kruskal-Wallis H Statistic | *p*-value (Kruskal-Wallis) | Mean Difference | *p*-value (Post-hoc Tukey) |
|---|---|---|---|---|
| Taganilao vs Lawigan | 12.94 | *0.001294 | -42.12 | 0.105100 |
| Taganilao vs Pujada Island | | | -108.47 | *0.000273 |
| Lawigan vs Pujada Island | | | -66.35 | *0.043490 |

*Note:* *difference is significant when *p*-value is < 0.05.

### Bray-Curtis Similarity Index

The dendrogram in Figure 5, based on the Bray-Curtis similarity index, shows distinct clustering of seagrass species composition across the three Pujada Bay sites. Taganilao clustered separately from Lawigan and Pujada Island, reflecting marked differences in species composition likely driven by higher anthropogenic disturbance. The similarity between Taganilao and Lawigan was moderate (0.5421), while Taganilao and Pujada Island showed lower similarity (0.4209), indicating greater compositional differences. Lawigan and Pujada Island had the highest similarity (0.5657), suggesting that despite moderate human activity at Lawigan, its seagrass community remains more similar to the pristine conditions of Pujada Island. These results align with Zhang et al. (2023), who reported that high disturbance often leads to homogenised and less diverse communities, and with Griffin et al. (2024), who found that moderate disturbance can still allow for ecological characteristics resembling undisturbed sites. The closer clustering of Lawigan and Pujada Island suggests that moderate activities like small-scale agriculture and fishing have not fully degraded Lawigan's ecosystem, which retains enough natural characteristics to support diverse and balanced seagrass communities. This highlights the potential for maintaining healthy seagrass habitats through effective management in moderately impacted areas, echoing the observations of Strachan et al. (2022) on balancing human use and ecological integrity in coastal ecosystems.

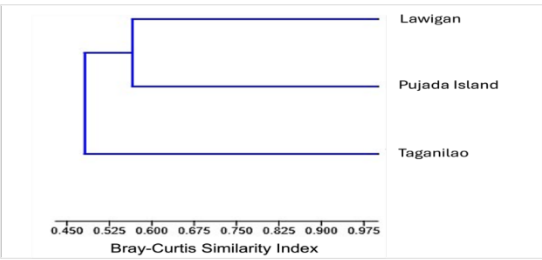


*Figure 5.* Bray-Curtis Similarity Index analysis showing the similarity in seagrass species composition across three sites in Pujada Bay

### Water Quality Parameters

The average water quality values across the three sites in Pujada Bay (Table 5) showed slight but notable variations, all within ranges suitable for healthy seagrass growth. Dissolved oxygen levels were consistently high, with Pujada Island recording the highest mean value (6.90 mg/L), followed closely by Lawigan (6.85 mg/L) and Taganilao (6.83 mg/L), indicating good oxygen availability across the bay. These similar values suggest that tidal exchange, depth, and biological activity are relatively uniform, preventing oxygen-limiting conditions, consistent with Tu et al. (2025), who emphasized the role of adequate DO in supporting seagrass health. pH values were near-neutral to slightly alkaline at Taganilao (8.14) and Lawigan (8.15), while Pujada Island was slightly lower (7.93), possibly due to local organic matter decomposition or shifts in carbonate buffering capacity. All values remain within the optimal marine range described by Cossa et al. (2024), indicating that pH is not a significant stressor.

Salinity levels showed minor variation, with Taganilao having the highest average (34.33‰), followed by Lawigan (33.33‰) and Pujada Island (33.00‰), reflecting natural influences such as hydrodynamics, freshwater inputs, and tidal patterns, as noted by Peng et al. (2024). Temperature was highest at Pujada Island (30.53 $^{o}$C), slightly lower at Lawigan (29.87 $^{o}$C), and lowest at Taganilao (29.43 $^{o}$C), likely influenced by factors such as water depth, sunlight exposure, and local currents. Marbà et al. (2022) observed that such moderate variations are unlikely to threaten seagrass unless they exceed tolerance thresholds for extended periods. Low standard deviations across parameters indicate stable and consistent conditions within each site, suggesting that water quality is not a limiting factor for seagrass growth in Pujada Bay, though subtle site-specific differences may still influence community composition and abundance.

*Table 5.* Average values of water quality parameters across the study sites

| Site | Parameter | Mean | Median | Standard deviation |
|---|---|---|---|---|
| Taganilao | DO (mg/L) | 6.83 | 6.83 | ± 0.02 |
| | pH | 8.14 | 8.14 | ± 0.02 |
| | Salinity (‰) | 34.33 | 35.00 | ± 1.15 |
| | Temperature ($^{o}$C) | 29.43 | 29.40 | ± 0.06 |
| Lawigan | DO (mg/L) | 6.85 | 6.85 | ± 0.04 |
| | pH | 8.15 | 8.14 | ± 0.02 |
| | Salinity (‰) | 33.33 | 33.00 | ± 1.53 |
| | Temperature ($^{o}$C) | 29.87 | 29.90 | ± 0.06 |
| Pujada Island | DO (mg/L) | 6.90 | 6.85 | ± 0.09 |
| | pH | 7.93 | 7.94 | ± 0.04 |
| | Salinity (‰) | 33.00 | 33.00 | ± 1.00 |
| | Temperature ($^{o}$C) | 30.53 | 30.50 | ± 0.06 |

**CCA of seagrass and environmental variables**

The Canonical Correspondence Analysis (CCA) results (Fig. 6) revealed strong relationships between seagrass species composition and environmental gradients, DO, pH, salinity, and temperature, across the three Pujada Bay sites. Axis 1 explained 80.34% of the total variance, indicating that it captured most of the environmental influence on species distribution, while Axis 2 accounted for 14.14%. *C. rotundata* and *E. acoroides* were positioned toward the positive end of Axis 1, closely associated with higher temperatures and DO levels, suggesting adaptation to warm, oxygen-rich environments. This pattern was most evident in Lawigan, which also plotted on the positive side of Axis 1, reflecting conditions favorable to these species. *S. isoetifolium*, positioned near the centre of the ordination plot, exhibited broad environmental tolerance, occurring in a range of conditions across sites.

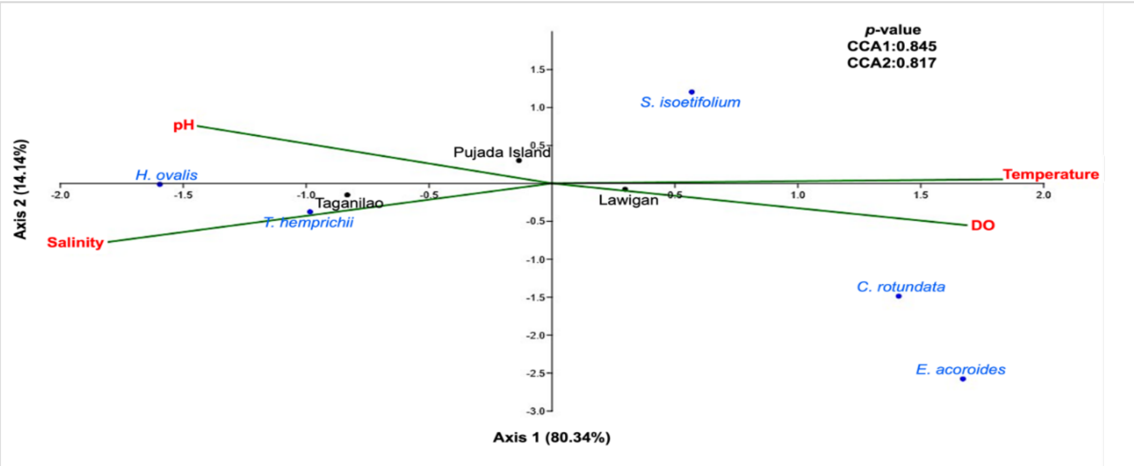


*Figure 6.* Canonical Correspondence Analysis biplot showing the relationships between seagrass species and environmental variables across the study sites. The plot illustrates the distribution of seagrass species (represented by blue circles) in relation to environmental variables (represented by green vectors), including DO, pH, salinity, and temperature

On the negative side of Axis 1, *T. hemprichii* and *H. ovalis* were associated with lower pH and DO, conditions typical of sheltered or more eutrophic areas with higher organic matter and decomposition rates. These environmental conditions align with those at Taganilao, a site with higher anthropogenic activity that contributes to cooler waters, reduced oxygen, and nutrient enrichment, favoring species adapted to such habitats. In contrast, Pujada Island was located near the plot centre, indicating a balanced mix of environmental factors and minimal disturbance, which supports a diverse assemblage of species with varying tolerances. These findings are consistent with previous studies (Vieira et al., 2022; Li et al., 2025) that emphasize the role of temperature and DO in shaping seagrass communities and highlight the capacity of undisturbed sites to maintain stable environmental gradients that promote biodiversity.

## CONCLUSION

The study highlights the significant impact of anthropogenic pressures on seagrass biodiversity in Pujada Bay. While Pujada Island represents a pristine baseline, Taganilao is heavily impacted by human activity, showing lower biodiversity and more dominated communities, whereas Lawigan exhibits a more balanced seagrass ecosystem. These findings emphasize the need for conservation measures to protect undisturbed habitats and reduce human-induced disturbances in more impacted areas. To ensure the long-term health of seagrass ecosystems, efforts should focus on reducing pollution, sedimentation, and land reclamation, particularly in Taganilao. Continuous monitoring of seagrass diversity and environmental parameters, and stronger coastal management policies, is crucial. Future research should explore the specific environmental factors influencing seagrass distribution, the effects of climate change, and the potential for restoration in degraded areas. By addressing these recommendations, we can support the recovery and sustainability of seagrass ecosystems in Pujada Bay and other similar coastal regions.

***Acknowledgements:*** We sincerely extend our gratitude to the Foreign-Assisted and Special Projects Service (FASPS) for their generous funding and support through the Dugongs and Marine Turtles Spatial Distribution and Density Analysis Project, which made this study possible.

## REFERENCES

Amone-Mabuto M., Mubai M., Bandeira S., Shalli M. S., Adams J. B., Lugendo B. R., Hollander J., 2023. Coastal communities' perceptions on the role of seagrass ecosystems for coastal protection and implications for management. *Ocean & coastal management*, 244: 106811. https://doi.org/10.1016/j.ocecoaman.2023.106811

Angsinco-Jimene L., Nogodula R., Tans D., 2003. Assessment of seagrass and macrobenthic algae in Pujada Bay, Mati, Davao Oriental. *Davao Research Journal*, 6(1): 1−11. https://doi.org/10.59120/drj.v6i1.46

Arriesgado D., Arriesgado E., Roa E., Perpetua A., Gonzales R., Acuña R., Sornito M., 2024. Seagrass cover and associated macrobenthic marine invertebrates in Southern Philippines. *Aquatic Ecology*, 58(3): 643−657. https://doi.org/10.1007/s10452-024-10095-5

Atencio J. M., Delostrico R. Q., Reynaldo H. N., Metillo E. B., 2024. The state of seagrass community in Panguil Bay, Southern Philippines. *AACL Bioflux*, 17(6).

Connolly R. M., Jackson E. L., Macreadie P. I., Maxwell P. S., O'Brien K. R., 2018. Seagrass dynamics and resilience. In *Seagrasses of Australia: Structure, ecology and conservation* Cham: 197−212. Springer International Publishing. https://doi.org/10.1007/978-3-319-71354-0_7

Cossa D., Infantes E., Dupont S., 2024. Hidden cost of pH variability in seagrass beds on marine calcifiers under ocean acidification. *Science of the Total Environment*, 915: 170169. https://doi.org/10.1016/j.scitotenv.2024.170169

Felix M., Ybañez Jr C., Macusi E. 2022. Assemblages of Benthic Foraminifera in Pujada Island, Davao Oriental, Philippines. *Davao Research Journal*, 13(1): 1−1. https://doi.org/10.59120/drj.v13i1.92

Griffin K. J., Johnston E. L., Poore A. G., Verges A., Clark G. F., 2024. Reducing direct physical disturbance also mitigates hidden drivers of decline in a threatened seagrass meadow. *Frontiers in Conservation Science*, 5: 1463637. https://doi.org/10.3389/fcosc.2024.1463637

Hastings R., Cummins V., Holloway P., 2020. Assessing the impact of physical and anthropogenic environmental factors in determining the habitat suitability of seagrass ecosystems. *Sustainability*, 12(20): 8302. https://doi.org/10.3390/su12208302

Hordijk I., Maynard D. S., Hart S. P., Lidong M., Ter Steege H., Liang J., Pfautsch S., 2023. Evenness mediates the global relationship between forest productivity and richness. *Journal of Ecology*, 111(6): 1308−1326. https://doi.org/10.1111/1365-2745.14098

Kinamot V. B., 2024. Influence of seagrass traits on the diversity of endophytic fungi. *Biodiversitas Journal of Biological Diversity*, 25(3). https://doi.org/10.13057/biodiv/d250342

Lanyon J. M., Sneath H. L., Long T., Blanshard W. H., Worthy G. A., Booth D. T., 2024. How much seagrass does a dugong need? Metabolic rate of live wild dugongs, Dugong dugon, determined through indirect calorimetry (oxygen consumption). *Marine Mammal Science*: e13190. https://doi.org/10.1111/mms.13190

Li Z., Li H., Zhang M., Zhang L., Li J., Liu J. 2025. Physiological and Molecular Responses of Tropical Seagrass Enhalus acoroides Exposed to Simultaneous High Temperature and Hypoxia Stress. *Marine Environmental Research*: 106997. https://doi.org/10.1016/j.marenvres.2025.106997

Lima M., D. A. C., Bergamo T. F., Ward R. D., Joyce C. B., 2023. A review of seagrass ecosystem services: providing nature-based solutions for a changing world. *Hydrobiologia*, 850(12): 2655−2670. https://doi.org/10.1007/s10750-023-05244-0

Liu S., Huang Y., Luo H., Ren Y., Jiang Z., Wu Y., Huang X., 2025. How Does Seagrass Cope with Eutrophication? From Stress Responses to Molecular Adaptive Mechanisms. *Current Pollution Reports*, 11(1): 42. https://doi.org/10.1007/s40726-025-00374-6

Ma X., Vanneste S., Chang J., Ambrosino L., Barry K., Bayer T., Van de Peer Y., 2024. Seagrass genomes reveal ancient polyploidy and adaptations to the marine environment. *Nature plants*, 10(2): 240−255. https://doi.org/10.1038/s41477-023-01608-5.

Magapan C. A., Ybañez Jr C. O., 2025. First Survey of Land Snails in Mount Hamiguitan: Biodiversity and Environmental Insights from a UNESCO World Heritage and ASEAN Heritage Park in the Philippines. *Zoological Studies*, 64(36): https://doi.org/10.6620/ZS.2025.64-36

Marbà N., Jordà G., Bennett S., Duarte C. M., 2022. Seagrass thermal limits and vulnerability to future warming. *Frontiers in Marine Science*, 9: 860826. https://doi.org/10.3389/fmars.2022.860826

McCloskey R. M., Unsworth R. K., 2015. Decreasing seagrass density negatively influences associated fauna. *PeerJ*, 3: e1053. https://doi.org/10.7717/peerj.1053

McMahon K., Kilminster K., Canto R., Roelfsema C., Lyons M., Kendrick G. A., Udy J. 2022. The risk of multiple anthropogenic and climate change threats must be considered for continental scale conservation and management of seagrass habitat. *Frontiers in Marine Science*, 9: 837259. https://doi.org/10.3389/fmars.2022.837259

Moreira-Saporiti A., Teichberg M., Garnier E., Cornelissen J. H. C., Alcoverro T., Björk M., Santos R., 2023. A trait-based framework for seagrass ecology: Trends and prospects. *Frontiers in Plant Science*, 14: 1088643. https://doi.org/10.3389/fpls.2023.1088643

Nordlund L. M., Unsworth R. K., Wallner-Hahn S., Ratnarajah L., Beca-Carretero P., Boikova E., Wilkes R., 2024. One hundred priority questions for advancing seagrass conservation in Europe. *Plants, People, Planet*, 6(3): 587−603. https://doi.org/10.1002/ppp3.10486

Nugraha A. H., Bengen D. G., Kawaroe M., 2017. Physiological response of Thallasia hemprichii on antrophogenic pressure in Pari Island, Seribu Islands, DKI Jakarta. *Ilmu Kelautan*, 22(1): 40−48. https://doi.org/10.14710/ik.ijms.22.1.40-48

Olive I., García-Robledo E., Silva J., Pintado-Herrera M. G., Santos R., Kamenos N. A., Frouin P., 2022. Contribution of the seagrass Syringodium isoetifolium to the metabolic functioning of a tropical reef lagoon. *Frontiers in Marine Science*, 9: 867986. https://doi.org/10.3389/fmars.2022.867986

Peng K., Yan L., Xie X., Deng Y., Gan Y., Zhang Y., 2024. Hydrogeochemical dynamics under saltwater-freshwater mixing in a mangrove wetland over tidal cycles. *Science of The Total Environment*, 954: 176827. https://doi.org/0.1016/j.scitotenv.2024.176827

Pislan H. T., Ybañez Jr C. O., 2024. Copepod distribution and diversity in the coastal areas of Ban-ao and Lambajon, Davao Oriental, Philippines: Environmental influences and conservation implications. *Davao Research Journal*, 15(2): 50−65. https://doi.org/10.59120/drj.v15iNo.2.185

Qin L. Z., Suonan Z., Kim S. H., Lee K. S., 2021. Growth and reproductive responses of the seagrass Zostera marina to sediment nutrient enrichment. *ICES Journal of Marine Science*, 78(3): 1160−1173. https://doi.org/10.1093/icesjms/fsab031

Rahayu Y. P., Kusumaningtyas M. A., Daulat A., Rustam A., Suryono D. D., Salim H. L., Adi N. S., 2023. Sedimentary seagrass carbon stock and sources of organic carbon across contrasting seagrass meadows in Indonesia. *Environmental Science and Pollution Research*, 30(43): 97754−97764. https://doi.org/10.1007/s11356-023-29257-3

Reyes A. G. B., Vergara M. C. S., Blanco A. C., Salmo III S. G., 2022. Seagrass biomass and sediment carbon in conserved and disturbed seascape. *Ecological Research*, 37(1): 67−79.

Shen J., Wu Z., Yin L., Chen S., Cai Z., Geng X., Wang D., 2022. Physiological basis and differentially expressed genes in the salt tolerance mechanism of Thalassia hemprichii. *Frontiers in Plant Science*, 13: 975251. https://doi.org/10.3389/fpls.2022.975251

Soissons L. M., Li B., Han Q., Van Katwijk M. M., Ysebaert T., Herman P. M., Bouma, T. J., 2016. Understanding seagrass resilience in temperate systems: the importance of timing of the disturbance. *Ecological indicators*, 66: 190−198. https://doi.org/10.1016/j.ecolind.2016.01.030

Strachan L. L., Lilley R. J., Hennige S. J., 2022. A regional and international framework for evaluating seagrass management and conservation. *Marine Policy*, 146: 105306. https://doi.org/10.1016/j.marpol.2022.105306

Suriya C., Satian C., Visut B., Supadha K., 2022. Diversity of freshwater fish at sago palm wetlands, Nakhon Si Thammarat province, Thailand. *Biodiversitas Journal of Biological Diversity*, 23(12). https://doi.org/10.13057/biodiv/d231230

Swadling D. S., West G. J., Gibson P. T., Laird R. J., Glasby T. M., 2023. Multiscale assessments reveal changes in the distribution of the endangered seagrass Posidonia australis and the role of disturbances. *Marine Biology*, 170(11): 147. https://doi.org/10.1007/s00227-023-04279-0

Tang K. H. D., Hadibarata T., 2022. Seagrass meadows under the changing climate: A review of the impacts of climate stressors. *Research in Ecology*, 4(1): 27−36. https://doi.org/10.30564/re.v4i1.4363

Tapilatu R. F., Wona H., Mofu B., Kolibongso D., Alzair N., Erdmann M., Maruanaya B., 2022. Foraging habitat characterization of green sea turtles, Chelonia mydas, in the Cenderawasih Bay, Papua, Indonesia: Insights from satellite tag tracking and seagrass survey. *Biodiversitas Journal of Biological Diversity*, 23(6). https://doi.org/10.13057/biodiv/d230601

Tu T. H., Lin E. J., Hung C. C., Chou W. C., Shih Y. Y., 2025. The dissolved oxygen variation in seagrasses is influenced by DOC excretion and its associated microbes. *Estuarine, Coastal and Shelf Science*, 313: 109080. https://doi.org/10.1016/j.ecss.2024.109080

Unsworth R. K., Cullen-Unsworth L. C., Jones B. L., Lilley R. J., 2022. The planetary role of seagrass conservation. *Science*, 377(6606): 609−613. https://doi.org/10.1126/science.abq6923

Vieira V. M., Lobo-Arteaga J., Santos R., Leitão-Silva D., Veronez A., Neves J. M., Pettersen M. R., 2022. Seagrasses benefit from mild anthropogenic nutrient additions. *Frontiers in Marine Science*, 9: 960249. https://doi.org/10.3389/fmars.2022.960249

Wang X. Y., Ge Y., Gao S., Chen T., Wang J., Yu F. H., 2021. Evenness alters the positive effect of species richness on community drought resistance via changing complementarity. *Ecological Indicators*, 133: 108464. https://doi.org/10.1016/j.ecolind.2021.108464

Ybañez Jr C. O., 2024. Exploring meiofaunal assemblages in Pujada Bay, Philippines: A glimpse into one of the world's most beautiful bays. *Biodiversitas Journal of Biological Diversity*, 25(5). https://doi.org/10.13057/biodiv/d250511

Ybañez Jr C. O., Gonzales R. C., 2023. Challenges and progress of grouper aquaculture in asia: A Review. *Davao Research Journal*, 14(2): 6−29. https://doi.org/10.59120/drj.v14i2.109

Zalsos J. D., Arriesgado D. M., Arriesgado E. M., Acuña R. E., 2021. Assessment and valuation of commercially important bivalves and gastropods within the seagrass beds of Laguindingan, Misamis Oriental and Rizal, Zamboanga del Norte, Philippines. *J Environ Aquat Resour*, 6: 16−34. https://doi.org/10.48031/msunjear.2021.06.02

Zhang Y., Yu X., Chen Z., Wang Q., Zuo J., Yu S., Guo R., 2023. A review of seagrass bed pollution. *Water*, 15(21): 3754. https://doi.org/10.3390/w15213754