Biodiversity and Conservation Status of Bivalves in the Intertidal Zones of Murcielagos Bay, Philippines

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Abstract

Bivalves play a crucial role in maintaining coastal ecosystems and supporting local fisheries, yet baseline data on their biodiversity and conservation status remain critically scarce. To address this research gap, this study assessed the biodiversity, species composition, and conservation status of bivalves in the intertidal zones of Murcielagos Bay, Zamboanga del Norte, and Misamis Occidental, Philippines. A descriptive ecological survey using 50-m line transects and 1 × 1 m quadrats was conducted across four municipalities (Sibutad, Rizal, Sapang Dalaga, and Baliangao) from June to September 2025 during the southwest monsoon (Habagat). Results identified 28 bivalve species across 14 families, with Veneridae the most species-rich. Diversity indices showed spatial variation across municipalities, with Rizal exhibiting the highest diversity (H′ = 1.99; D = 0.81) and Baliangao the lowest (H′ = 0.89; D = 0.34), largely influenced by the dominance of Modiolus modulaides. Overall, low-to-moderate diversity was linked to substrate heterogeneity. All recorded species are currently classified as Not Evaluated (NE) by the International Union for Conservation of Nature (IUCN). The dominance of filter-feeding species suggests a productive environment potentially influenced by anthropogenic inputs, although this was not directly measured. This lack of formal risk assessments for these species highlights a critical data gap, necessitating localized conservation strategies and community-based monitoring in partnership with the LGUs and the community to ensure the long-term sustainability of marine resources in Murcielagos Bay.

Keywords: Abundance, Bivalves, Coastal Biodiversity, Conservation Status, Intertidal ecology, Marine ecology, Murcielagos Bay, Species composition

Introduction

Marine biodiversity plays a vital role in maintaining the ecological balance and sustainability of coastal ecosystems. Among the key marine organisms contributing to these ecosystems are bivalves, which serve critical ecological functions as both prey and predators in marine food webs. Mollusks are crucial ecosystem engineers, shaping aquatic bottom environments and providing habitat, protection, and food for a diverse range of species (Gusmao et al., 2024; Ysebaert et al., 2018). They also contribute significantly to water filtration, habitat stability, trophic interactions, and nutrient cycling (Vaughn & Hoellein, 2018). Numerous international studies have emphasized the need to establish baseline data on bivalve assemblages to assess ecosystem health and develop effective conservation strategies. Despite their ecological importance, these species are often overlooked in marine resource assessments and conservation planning compared with commercially significant finfish and coral reef ecosystems.

In Indonesia, the pressure from human activity on marine life is a significant concern. Sahidin et al. (2019) assessed the biodiversity and spatial distribution of mollusks in the coastal waters of Tangerang, an area heavily impacted by anthropogenic activities. Habitat heterogeneity plays a crucial role in bivalve species richness. In Malaysia, Vian et al. (2022) investigated bivalve diversity in seagrass beds at Pulau Gazumbo, noting that sediment characteristics and the structural complexity of seagrass roots significantly influenced spatial distribution. They found that highly fine sediments with excessive organic content could have detrimental, smothering effects on certain filter-feeding bivalves when hydrodynamic flushing is poor.

The influence of habitat type is further supported by Kurniawan et al. (2024), who studied bivalve communities along the south coast of Pamekasan, Madura Island, Indonesia. Consistent with Vian et al. (2022), Kurniawan et al. (2024) concluded that substrate architecture and the presence of mangroves were primary drivers of bivalve diversity and abundance. Similarly, in the coral ecosystems of the Mexican Tropical Pacific, Barrientos Luján et al. (2021) examined the spatial heterogeneity of benthic macrofauna. Their research highlighted that complex, hard-substrate habitats, such as coral reefs, support distinct epifaunal bivalve assemblages.

Beyond ecology, bivalves have immense socioeconomic importance. Kurniawan et al. (2024) noted that many bivalve species, such as Solen sp., *Anadara antiquata*, and *Meretrix meretrix*, are routinely gathered and consumed by coastal communities, providing critical sources of protein and income. However, these valuable resources are under significant pressure. Kurniawan et al. (2024) and Vaughn and Hoellein (2018) warn that bivalve populations face severe threats from habitat destruction, overharvesting, and coastal pollution. To protect these populations, conservation efforts must focus on habitat restoration, pollution control, and sustainable harvesting practices.

Assessment studies across the Philippines consistently highlight the strict substrate requirements of bivalves in intertidal zones. In the mudflats of Banate Bay, Iloilo, Flores et al. (2014) conducted a diversity assessment that established a baseline for local gleaning grounds. Their study noted that bivalves require specific conditions, such as stable sediment depth and organic content, to thrive and burrow effectively. This localized substrate specificity was corroborated by Arabaca et al. (2022) in Ajuy, Iloilo, and by Caril et al. (2023) in Caramoan, Camarines Sur, who both found that bivalve diversity is heavily restricted to distinct patches of optimal sediment matrices within the intertidal flats.

In Palawan, Dolorosa and Dangan-Galon (2014) documented bivalve species richness in the Iwahig River-Estuary. Their results suggest that river-estuary systems serve as critical transition zones that support unique assemblages. They noted that commercially important species, such as the blood cockle Anadara uropigimelana, exhibited distribution patterns that bridge mangrove forests and riverbeds. Similarly, Jamodiong and Lacuna (2018) assessed the intertidal zones of

Butuan Bay; they noted that although overall biodiversity was moderate, the exclusive presence of economically valuable bivalves underscored the area's crucial importance for local food security.

Tidal exposure-driven zonation is another critical factor in bivalve spatial distribution. Cañada et al. (2021) analyzed bivalve zonation in the mangrove forests of Casiguran, Aurora. Their results showed distinct species preferences for specific tidal levels, driven by desiccation tolerance. For instance, the bivalve Gafrarium tumidum was strictly restricted to the lower, wetter zones, where prolonged submersion allows extended filter-feeding. In Eastern Bohol, Libres (2015) compared mangrove and seagrass ecosystems, highlighting that filter-feeding bivalves like Anadara antiquata were significantly more common in the cleaner, structurally complex waters of seagrass beds.

Murcielagos Bay, spanning Zamboanga del Norte and Misamis Occidental in the Philippines, is an important coastal ecosystem that supports diverse marine life and small-scale fisheries. The bay provides habitat for benthic species, including bivalves, which are economically valuable to local fisheries. However, growing human activities, such as overfishing, habitat degradation, and coastal pollution, pose significant threats to these species, potentially leading to population declines and habitat loss (FAO, 2020). Additionally, climate change-driven factors, including rising sea temperatures and ocean acidification, may affect species distributions and reproductive cycles (Golikov et al., 2024). Despite these threats, there remains a significant lack of scientific studies examining the biodiversity, spatial distribution, and conservation status of bivalves in Murcielagos Bay.

The lack of localized baseline data makes it difficult to develop robust management guidelines, limiting the formulation of science-based conservation policies (Ullah et al., 2023). These localized policies are essential for protecting biodiversity and ensuring the sustainability of small-scale fisheries that depend heavily on these species (Imbwae et al., 2023). Without strengthening localized research and understanding specific socio-economic and ecological contexts, comprehensive policy support measures often prove ineffective (Xiong et al., 2024). This knowledge gap hinders effective resource management and conservation planning, as policymakers and resource managers lack site-specific data on species diversity, population dynamics, and environmental influences on these important marine organisms.

To address this research gap, this study aims to assess the biodiversity, species composition, and conservation status of bivalves in Murcielagos Bay. The findings will contribute to the Ecosystem Approach to Fisheries Management (EAFM) and support the implementation of conservation policies under the Philippine Fisheries Code (RA 10654). The study also aligns with the Zamboanga Peninsula Regional Development and Innovation Research Agenda (RDIRA) 2023–2028, which prioritizes marine resource sustainability and biodiversity protection.

By providing scientifically grounded data, this research will help marine biologists, policymakers, and local communities develop effective conservation strategies to ensure the long-term sustainability of bivalves in Murcielagos Bay. Furthermore, this study will contribute to broader marine conservation efforts in the Philippines, supporting the goals of SDG 14 (Life Below Water) within the United Nations Sustainable Development Goals (SDGs).

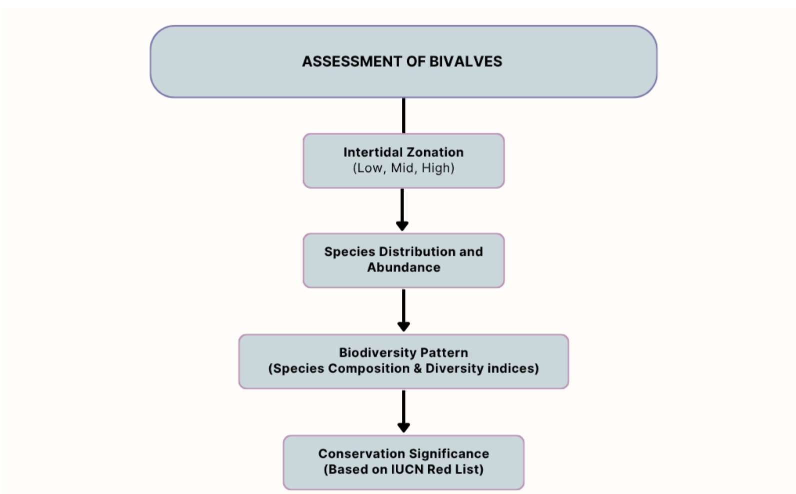
Theoretical and Conceptual Framework

The Ecosystem Approach to Fisheries Management (EAFM) is a science-based framework that recognizes the complex interconnections among fisheries, ecological systems, and socio-economic factors (FAO, 2020). Unlike conventional fisheries management, which focuses primarily on maximizing harvest yields, EAFM integrates ecological sustainability, governance structures, and socio-economic considerations (Link & Marshak, 2019). This approach is particularly relevant for managing bivalves, as these species play critical ecological roles in marine food webs, contribute to benthic habitat stability, and support coastal fisheries and local livelihoods.

At its core, EAFM is grounded in systems theory, which holds that fisheries should be understood as interdependent components of larger ecological networks, necessitating adaptive, multi-scale governance (FAO, 2020). This aligns with resilience theory, which emphasizes an ecosystem's ability to adapt to and recover from environmental and human-induced disturbances, ensuring long-term sustainability (Folke et al., 2016). Moreover, common-pool resource theory, as introduced by Ostrom (2009), underscores the need for community participation in fisheries governance and advocates co-management models that integrate scientific data with local ecological knowledge to enhance conservation and sustainable resource use.

In the Philippines, the Bureau of Fisheries and Aquatic Resources (BFAR) has institutionalized EAFM as a national strategy for fisheries governance, aligning it with the Philippine Fisheries Code (Republic Act 10654) and with international commitments, including the United Nations Sustainable Development Goals (SDG 14: Life Below Water) (BFAR, 2023).

Figure 1. *Conceptual Framework illustrating how intertidal zonation (low, mid, high zones) structures the distribution and abundance of bivalves, which in turn determines biodiversity patterns and serves as the basis for assessing conservation significance using the IUCN Red List of Threatened Species*

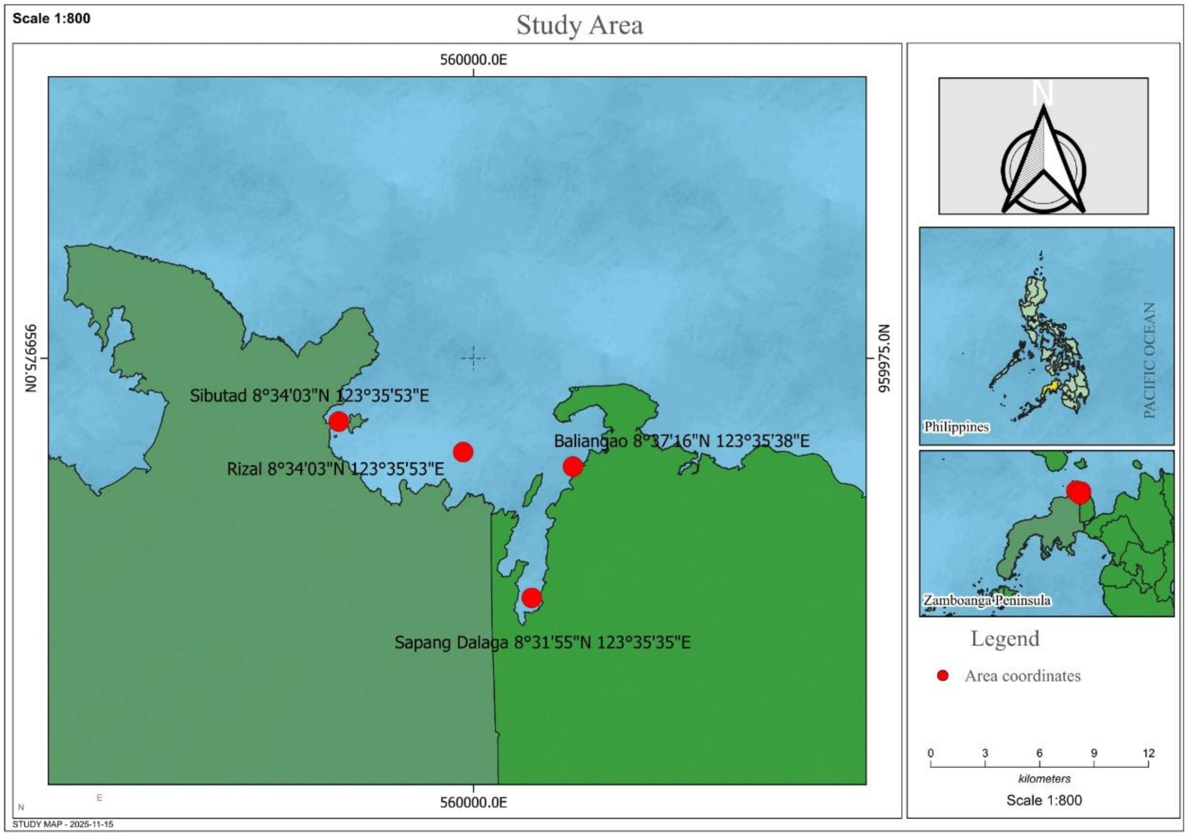


Materials and Methods

A descriptive and ecological survey design was used to document species composition, abundance, diversity index, spatial distribution, and conservation status of mollusks and echinoderms in Murcielagos Bay. Sampling was conducted in the intertidal zones of four municipalities bordering Murcielagos Bay: Sibutad, Rizal, Sapang Dalaga, and Baliangao. Surveys were carried out from June to September 2025, during the southwest monsoon, coinciding with the lowest spring tides. An entry protocol was implemented to ensure a respectful and effective study in these municipalities. This process included securing necessary permits from Local Government Units (LGUs), and initial meetings were held with local leaders and stakeholders to explain the study's objectives, significance, and methods.

Murcielagos Bay, located in Zamboanga del Norte, Philippines, at approximately 8.5667° N latitude and 123.5000° E longitude, is bordered by the municipalities of Sibutad, Rizal, Sapang Dalaga, and Baliangao. To ensure accurate data collection, this study utilized precise GPS coordinates to identify sampling sites across these municipalities, allowing for a comprehensive assessment of populations within Murcielagos Bay and providing data for possible marine sanctuary establishment.

Figure 2. *Map showing the sampling areas.*



A 50-m line transect was laid parallel to the shoreline across the low, mid, and high intertidal zones. Along each transect, sampling was conducted at 5-m intervals. At each interval, a 1 × 1 m quadrat was placed on both sides of the transect line within a two-meter observation width (English et al., 1997). Two replicate transects were established per site, with a 10-m distance between them, yielding a total sampled area of 120 m2. All bivalves observed within each quadrat were photographed, identified, and recorded in situ, and the corresponding habitat type was noted for each sampling point. Species abundance was expressed as density, and diversity indices were calculated from the recorded data using the Shannon–Wiener Index (H′) and Simpson's Diversity Index (D). Higher H′ values indicate greater species richness and evenness, while Simpson's D approaching 1 indicates high diversity. Conservation status was verified using the IUCN Red List. The value of H′ ranges from 0 to 5, and can be interpreted based on the criteria given below (Ulfah et al., 2019):

Table 1 *Shannon-Weiner Index (H') Categorization.*

Shannon-Wiener Score (H′)	Interpretation
H′ ≤ 1	Low Diversity (Indicates high environmental stress or a community dominated by very few species)
1 < H′ ≤ 3	Moderate Diversity (Indicates a balanced community with a fair distribution of individuals among species)
H′ ≥ 3	High Diversity (Indicates a highly stable ecosystem with high species diversity) richness and evenness)

Another index that measures species diversity is the Simpson index. It accounts for both the number and abundance of species in a particular area (Guajardo, 2015). The Simpson score ranges from 0 to 1, where:

Table 2 *Simpson Index (D) Categorization.*

Simpson Score (*D*)	Interpretation
0.00	Absence of Diversity
0.01 – 0.40	Low Diversity
0.41 – 0.60	Moderate Diversity
0.61 – 0.80	Moderately High Diversity
0.81 – 0.99	High Diversity
1.00	Absolute Diversity

The physico-chemical profile of Murcielagos Bay was assessed through water quality measurements conducted at all sampling sites in Sibutad, Rizal, Sapang Dalaga, and Baliangao. In-situ measurements were integrated into the biological surveys, with data collected along 50-meter line transects across the low, mid, and high intertidal zones. A calibrated multiparameter water quality meter was used to simultaneously record pH, Total Dissolved Solids (TDS), and temperature. Complementing this, a pen-type portable dissolved oxygen meter was employed to measure Dissolved Oxygen (DO) levels. Salinity was measured using a salinity refractometer by adding droplets of water to the prism and reading it under bright light, noting the point at which the colors separate along the scale. To maintain data reliability and minimize contamination, triplicate readings were averaged for each transect, and all equipment was rinsed with distilled water between sites.

To ensure data reliability, all water quality instruments underwent standardized calibration before each sampling site and were used with distilled water for zeroing. Taxonomic accuracy was validated by cross-referencing in situ observations with the FAO Species Identification Guides and the World Register of Marine Species (WoRMS) database. All species identifications were further validated by the University of the Philippines Mindanao through a formal review of high-resolution photographic documentation.

Ethical clearance was granted by the Jose Rizal Memorial State University Research Ethics Committee (JRMSU REC) under Code 2026-070. The investigation was conducted in strict adherence to institutional ethical standards, ensuring non-destructive sampling techniques with minimal environmental impact, and necessary permits were obtained for fieldwork. Marine organisms were handled with care and returned to their habitats after observation. Data were collected and reported with transparency, ensuring accuracy and confidentiality. All field procedures and data collection strategies were verified by experts (UP Mindanao) to meet the ethical requirements. Research findings will be shared with stakeholders to support marine conservation and sustainable management efforts.

Limitations of the Study

While this study provides essential baseline data on the bivalve communities in Murcielagos Bay, there are several methodological limitations. First, the study is limited to a seasonal limitation, as sampling was exclusively conducted during the southwest monsoon (*Habagat*) from June to September 2025, which may not capture temporal shifts in species abundance or physico-chemical parameters occurring during other seasons. Second, the spatial distribution was limited to the intertidal zones of four municipalities (Sibutad, Rizal, Sapang Dalaga, and Baliangao); having other unsampled coastal areas within the bay may have additional, unrecorded bivalve assemblages. Finally, the reliance on non-destructive, *in situ* visual identification within quadrats introduces a detection bias, as it reduces the likelihood of observing highly cryptic or deeply infaunal species. Consequently, the recorded 28 bivalve species may be a conservative estimate, and future research should consider year-round sampling, broader spatial coverage, and supplementary sampling techniques to fully capture the bay's taxonomic diversity.

Results Discussion: Species Composition

A total of 28 species of bivalves from 14 families were recorded across all sites (Table 1). The family Veneridae was the most species-rich, represented by seven species (*Gafrarium aequivocum, G. pectinatum, G. tumidum, Meretrix lyrata, Paphia undulata, Pitar* sp., and *Tapes literatus*), followed by Arcidae (*Anadara antiquata, Barbatia virescens, Cucullaearca foliata*) and Pinnidae (*Atrina pectinata, Pinna bicolor, Pinna muricata*), each represented by three species. The remaining families, such as Cardiidae, Ostreidae, and Tellinidae, were represented by fewer species. Widely distributed species found across most sampling stations included the *Anadara antiquata*, *Vasticardium flavum*, *Modiolus modulaides*, and *Placuna ephippium*.

Table 3 *Species composition of bivalves across the different areas in Murcielagos Bay. Note: (+) indicates presence, while (-) indicates absence of each species at the surveyed areas.*

Family	Species	Sibutad	Rizal	Sapang Dalaga	Baliangao
Arcidae	*Anadara antiquata* (Linnaeus, 1758)	+	+	+	+
	Barbatia virescens (Reeve, 1844)	+	+	+	-
	Cucullaearca foliata (Forsskål, 1775)	+	-	-	-
Cardiidae	*Fulvia mutica* (Reeve, 1844)	-	+	-	-
	Vasticardium angulatum (Lamarck, 1819)	-	+	-	-
	Vasticardium flavum (Linnaeus, 1758)	+	+	+	+

Glycymerididae	*Tucetona pectunculus* (Linnaeus, 1758)	-	+	-	-
Isognomonidae	*Isognomon isognomum* (Linnaeus, 1758)	+	-	+	+
Lucinidae	*Fimbria fimbriata* (Linnaeus, 1758)	-	+	-	-
Mactridae	*Spisula sachalinensis* (Schrenck, 1861)	-	-	+	-
Malleidae	*Malleus malleus* (Linnaeus, 1758)	-	+	-	-
Modiolidae	*Modiolus modulaides* (Röding, 1798)	+	+	+	+
Ostreidae	*Magallana bilineata* (Röding, 1798)	+	-	-	-
	Saccostrea echinata (Qouy & Gaimard, 1835)	+	-	-	-
Pinnidae	*Atrina pectinata* (Linnaeus, 1767)	+	-	-	-
	Pinna bicolor (Gmelin, 1791)	+	-	-	+
	Pinna muricata (Linnaeus, 1758)	-	-	-	+
Placunidae	*Placuna ephippium* (Philipsson, 1788)	+	+	+	-
Spondylidae	*Spondylus sp.*	-	+	-	-
Tellinidae	*Scutarcopagia scobinata* (Linnaeus, 1758)	-	+	-	-
	Serratina sp.	-	+	-	+
Veneridae	*Gafrarium aequivocum* (Holten, 1802)	-	-	+	-
	Gafrarium pectinatum (Linnaeus, 1758)	-	-	-	+
	Gafrarium tumidum (Röding, 1797)	+	+	-	-
	Meretrix lyrata (G. B. Sowerby II, 1851)	-	+	-	-
	Paphia undulata (Born, 1778)	+	-	-	-
	Pitar sp.	-	+	+	+
	Tapes literatus (Linnaeus, 1758)	-	-	+	+

Figure 3. Species of Bivalves observed in Murcielagos Bay. (Family Arcidae)- A–B: *Anadara antiquata,* C: *Barbatia virescens,* D: *Cucullaearca foliata* (Family Cardiidae)- E: *Fulvia mutica,* F-G: *Vasticardium angulatum*, H-I: *Vasticardium flavum,* (Family Glycymerididae)-J: *Tucetona pectunculus,* (Family Isognomonidae)-K: *Isognomon isognomum,* (Family Lucinidae)-L: *Fimbria fimbriata.*

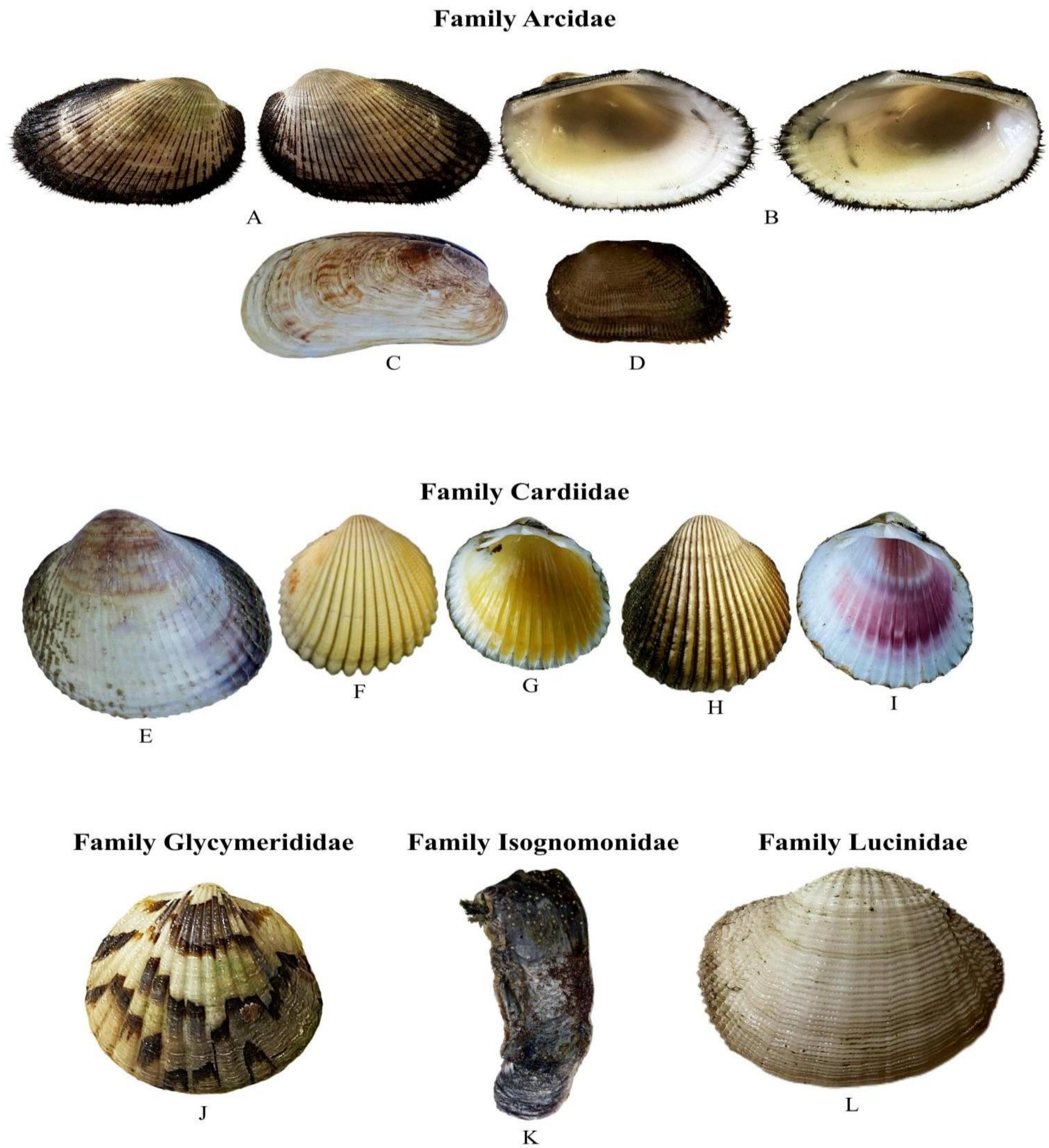


Figure 4. Species of Bivalves observed in Murcielagos Bay. (Family Mactridae)-M: *Spisula sachalinensis,* (Family Malleidae)-N: *Malleus malleus,* (Family Modiolidae)-O: *Modiolus modulaides,* (Family Ostreidae) P: *Magallana bilineata,* Q: *Saccostrea echinata,* (Family Pinnidae)-R: *Atrina pectinata,* S: *Pinna bicolor*, T: *Pinna muricata*, (Family Placunidae)- U: *Placuna ephippium*, (Family Spondylidae)-V: *Spondylus sp.*, (Family Tellinidae)-W: *Scutarcopagia scobinata,* X: *Serratina sp.*

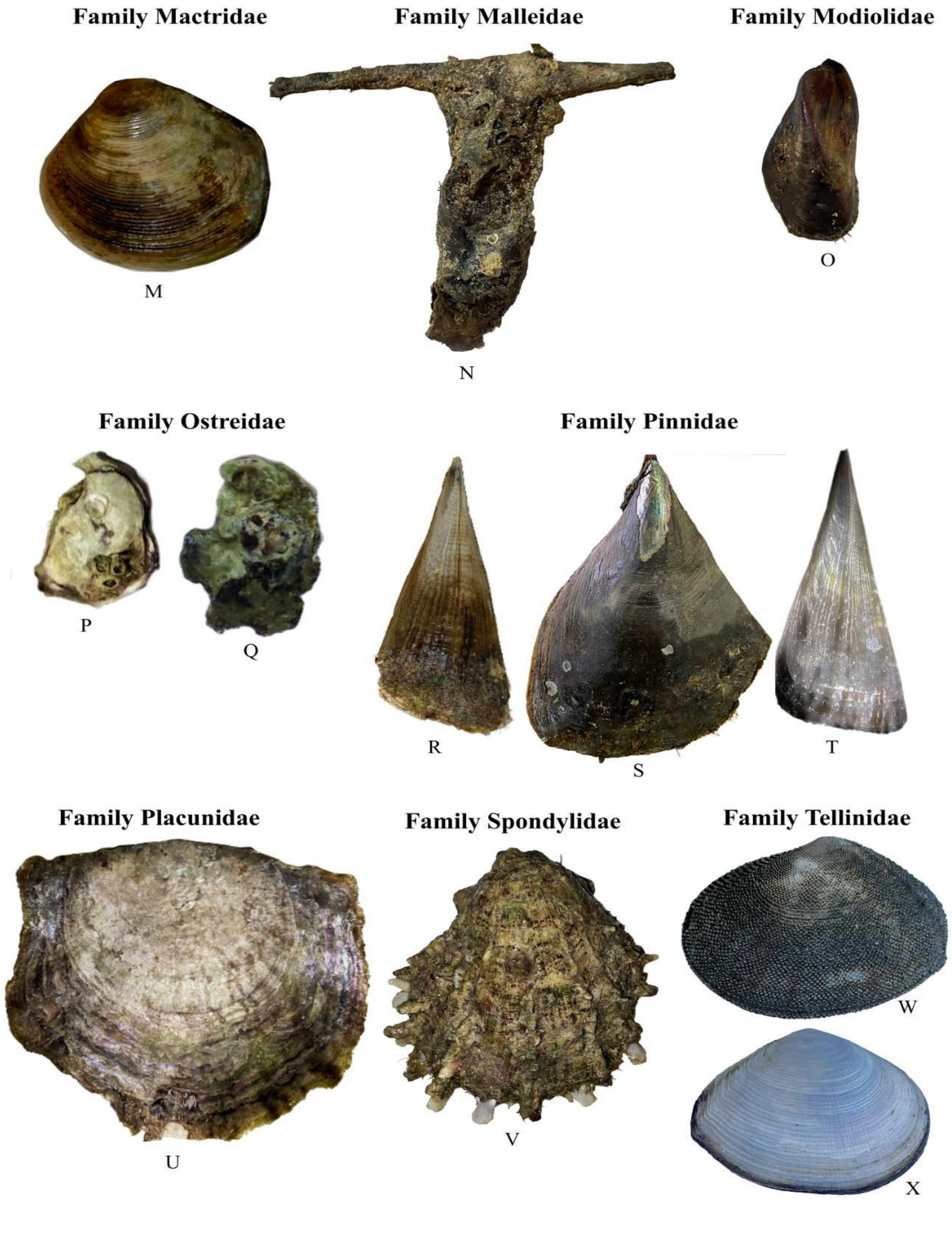
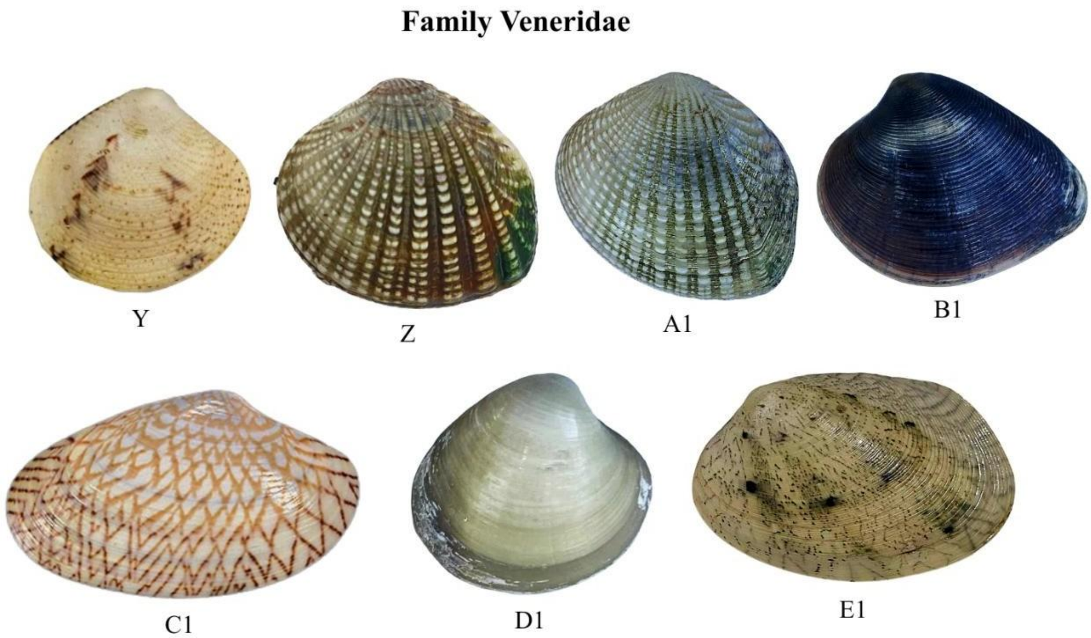


Figure 5. Species of Bivalves observed in Murcielagos Bay. (Family Veneridae)-Y: *Gafrarium aequivocum*, Z: *Gafrarium pectinatum*, A1: *Gafrarium tumidum*, B1: *Meretrix lyrata*, C1: *Paphia undulata*, D1: *Pitar sp.*, E1: *Tapes literatus*



The bivalve community in Sibutad is defined by the presence of oysters (Family Ostreidae), specifically *Magallana bilineata* and *Saccostrea echinata. Paphia undulata is also found here*. The exclusive occurrence of oysters in this locality indicates the availability of hard substrates or mangrove roots needed for their attachment. This contrasts with the soft-sediment habitats that burrowing species prefer at other stations (Cañada et al., 2021). Additionally, Sibutad's elevated alkalinity (pH 8.68) (Table 8) likely supports the calcification needs of these heavy-shelled species. Alkaline conditions promote calcium carbonate precipitation, which is necessary for shell formation (Molina et al., 2025).

Rizal demonstrated the highest species richness among the surveyed municipalities, including exclusive species such as *Fulvia mutica* (Cardiidae), *Tucetona pectunculus* (Glycymerididae), *Fimbria fimbriata* (Lucinidae), and *Spondylus* sp. (Spondylidae). Sapang Dalaga exhibited moderate diversity and was the only location where *Spisula sachalinensis* (Mactridae) and *Gafrarium aequivocum* (Veneridae) were identified. The occurrence of these burrowing species highlights the presence of sandy-mud intertidal substrates that are suitable for filter-feeders, a habitat type extensively documented in tropical intertidal studies (Hamli et al., 2017).

Baliangao recorded the presence of *Pinna muricata* and *Gafrarium pectinatum*, which were absent in other areas. However, it lacked the oyster and arc shell diversity observed in Sibutad. The Baliangao assemblage reflects an environment likely more exposed to currents, with sandy-muddy substrates that favor semi-infaunal species such as Pinna, which embed deeply in the sediment for stability (Picardal & Dolorosa, 2014). This contrasts with the oyster assemblages of Sibutad, which rely on hard substrates in sheltered mangrove zones, further highlighting how substrate type and hydrodynamic conditions drive spatial heterogeneity in bivalve communities (Vian et al., 2022).

The dominance of the family Veneridae in Murcielagos Bay aligns with national patterns of marine biodiversity in the Philippines. Similar studies by Caril et al. (2023) in Camarines Sur and Arabaca et al. (2022) also identified Veneridae as the most species-rich bivalve family in intertidal zones, citing their high adaptability to sediment types ranging from sandy to muddy substrates. The presence of economically important species such *as Anadara antiquata* and *Modiolus modulaides* across multiple municipalities highlights the bay's role in supporting local food security, a finding consistent with Ardines et al. (2020), who noted that these families are heavily gleaned for subsistence on offshore islands. However, the presence of *Placuna ephippium* (Windowpane oyster) across three municipalities is noteworthy. At the same time, this indicates soft-bottom habitats. Sahidin et al. (2019) warn that dominance of deposit-feeding bivalves can sometimes signal organic enrichment or degradation in coastal waters. Thus, while diversity is high, the composition, dominated by filter-feeding Veneridae and Arcidae, suggests a productive yet anthropogenically influenced ecosystem. They also conclude that a community structure skewed toward these suspension and deposit feeders may indicate organic enrichment from human activities, which supports high biomass of tolerant species even in disturbed environments.

Habitat Type

The spatial distribution of Class Bivalvia in Murcielagos Bay shows a strong association with substrate composition and localized habitat heterogeneity. A significant portion of the documented assemblage, including commercially valuable taxa such as *Anadara antiquata*, *Modiolus modulaides*, *Isognomon isognomum*, and *Gafrarium tumidum*, exhibits remarkable ecological plasticity. These species occupy muddy, rocky, sandy, and seagrass habitats. This widespread distribution across substrate types suggests adaptations to the dynamic physico-chemical conditions of the intertidal zone. The capacity of these bivalves to colonize highly heterogeneous environments aligns with the principles outlined by Barrientos-Luján et al. (2021), who emphasized that spatial variations in substrate architecture at local scales are the primary drivers of molluscan richness and community structure. By exploiting a combination of micro-habitats, these adaptable species effectively partition spatial resources and minimize competitive exclusion.

Presented in Table 2, several taxa demonstrate pronounced habitat specificity, highlighting the critical ecological role of specific benthic features. Species such as *Cucullaearca foliata*, *Malleus malleus*, *Atrina pectinata*, and *Gafrarium pectinatum* are exclusively associated with sandy substrates embedded within seagrass meadows.

Table 4. *Habitat Type of each bivalve species found in Murcielagos Bay.*

Family	Species	Habitat Type
Arcidae	*Anadara antiquata*	muddy, rocky, sandy, seagrass
	Barbatia virescens	muddy, rocky, sandy, seagrass
	Cucullaearca foliata	sandy, seagrass
Cardiidae	*Fulvia mutica*	sandy, seagrass
	Vasticardium angulatum	muddy, sandy, seagrass
	Vasticardium flavum	muddy, rocky, sandy, seagrass
Glycymerididae	*Tucetona pectunculus*	muddy, sandy, seagrass
Isognomonidae	*Isognomon isognomum*	muddy, rocky, sandy, seagrass
Lucinidae	*Fimbria fimbriata*	muddy, sandy, seagrass
Mactridae	*Spisula sachalinensis*	muddy, rocky, seagrass
Malleidae	*Malleus malleus*	sandy, seagrass
Modiolidae	*Modiolus modulaides*	muddy, rocky, sandy, seagrass
Ostreidae	*Magallana bilineata*	muddy, rocky, sandy, seagrass

	Saccostrea echinata	muddy, sandy
Pinnidae	*Atrina pectinata*	sandy, seagrass
	Pinna bicolor	muddy, rocky, sandy, seagrass
	Pinna muricata	sandy, seagrass
Placunidae	*Placuna ephippium*	muddy, rocky, sandy, seagrass
Spondylidae	*Spondylus sp.*	sandy, seagrass
Tellinidae	*Scutarcopagia scobinata*	sandy, seagrass
	Serratina sp.	muddy, sandy, seagrass
Veneridae	*Gafrarium aequivocum*	muddy, rocky, sandy, seagrass
	Gafrarium pectinatum	sandy, seagrass
	Gafrarium tumidum	muddy, rocky, sandy, seagrass
	Meretrix lyrata	muddy, sandy, seagrass
	Paphia undulata	muddy, rocky, sandy
	Pitar sp.	muddy, rocky, sandy, seagrass
	Tapes literatus	muddy, rocky, sandy, seagrass

Seagrass ecosystems provide essential structural complexity; their root-rhizome networks stabilize shifting sandy sediments and alter local hydrodynamic regimes, creating highly favorable micro-environments for infaunal and semi-infaunal bivalves. Vian et al. (2022) documented comparable distribution patterns, establishing that the architectural complexity of seagrass beds, interacting with fine sediment textures, serves as a crucial determinant for bivalve settlement and survival. This stabilizing effect is particularly vital for the Pinnidae family (e.g., *Atrina* and *Pinna* spp.), which require firm anchorage in soft, undisturbed sediments to maintain their vertical orientation and filter-feeding efficiency (del Norte-Campos et al., 2020).

Furthermore, the prevalence of muddy substrates significantly dictates the presence and abundance of specific taxa, such as *Saccostrea echinata*, *Meretrix lyrata*, and *Vasticardium angulatum*. Muddy intertidal flats, characterized by finer sediment and higher organic carbon retention, function as highly productive feeding grounds. Sahidin et al. (2019) demonstrated that sediment texture and organic matter content are principal parameters governing bivalve density; environments with stable, organic-rich muddy substrates consistently support higher population densities of suspension and deposit feeders compared to shifting, unstable sands. In Murcielagos Bay, the integration of muddy substrates within rocky crevices and seagrass roots likely facilitates the dense, mat-like aggregations observed in species like *Modiolus modulaides*.

The diverse habitat utilization patterns observed among the bivalves of Murcielagos Bay show the ecological importance of preserving coastal habitat heterogeneity. The coexistence of ecologically plastic species and substrate-specific species confirms that the bay's overall biodiversity is sustained by a composition of seagrass beds, rocky, and soft-sediment flats, which act as critical habitats for both ecological function and local livelihoods (Kurniawan et al., 2024). Consequently, localized conservation and management strategies must prioritize the protection of these interconnected benthic environments to prevent the decline of both diversity and commercially vital populations.

Abundance of Bivalves

The abundance of bivalves in Murcielagos Bay, expressed as density (individuals per 120 m^2 sampled area), reveals highly localized spatial distribution patterns linked to the benthic complexity of the four municipalities. As demonstrated in Table 3, the bivalve community is not uniformly distributed having species partition themselves across Sibutad, Sapang Dalaga, Rizal, and Baliangao based on specific substrate preferences ranging from dense seagrass meadows to organic-rich mudflats and rocky-sandy substrates. This strong habitat-species correlation aligns with the findings of Barrientos-Luján et al. (2021), who established that local-scale habitat heterogeneity acts as the primary driver of molluscan community structure and spatial richness.

Table 5. *Density of bivalves across sites and areas in Murcielagos Bay (individuals/120 m2). Legend: Can: Canim, Sin: Sinipay, Pang: Panganuran, Cas: Casul, Nap: Naputhaw, Nab: Naburos, Pmir: Punta Miray, Psul: Punta Sulong, Nang: Nangca, Nas: Nasipang.*

Family	**Species**	SIBUTAD			SAPANG DALAGA		RIZAL		BALIANGAO		
		Can	Sin	Pan	Cas	Nap	Nan	Nas	Nab	Pmir	Psul
Arcidae	*Anadara antiquata*	0.73	0.38	0.02	0.42	0.09	1.14	0.14	0.01	0.1	0.01
	Barbatia virescens	0.03	0	0	0.06	0.04	0	0.02	0	0	0
	Cucullaearca foliata	0	0.03	0	0	0	0	0	0	0	0
Cardiidae	*Fulvia mutica*	0	0	0	0	0	0	0.01	0	0	0
	Vasticardium angulatum	0	0	0	0	0	0.09	0.19	0	0	0
	Vasticardium flavum	0.03	0	0	0.1	0.08	0.03	0.57	0.03	0.11	0
Glycymerididae	*Tucetona pectunculus*	0	0	0	0	0	0	0.03	0	0.02	0
Isognomonidae	*Isognomon isognomum*	0.32	0	0	0.33	0.01	0	0	0.01	0	0.02
Lucinidae	*Fimbria fimbriata*	0	0	0	0	0	0.09	0	0	0	0
Mactridae	*Spisula sachalinensis*	0	0	0	0	0.03	0	0	0	0	0
Malleidae	*Malleus malleus*	0	0	0	0	0	0	0.08	0	0	0
Modiolidae	*Modiolous modulaides*	1.36	3.46	1.08	1.12	0.01	0.12	0.04	0.5	0	2.84
Ostreidae	*Magallana bilineata*	0.17	0	0.03	0	0	0	0	0	0	0
	Saccostrea echinata	0	0.03	0	0	0	0	0	0	0	0
Pinnidae	*Atrina pectinata*	0	0	0.01	0	0	0	0	0	0	0
	Pinna bicolor	0.01	0.01	0	0	0	0	0	0	0	0.14
	Pinna muricata	0	0	0	0	0	0	0	0	0.12	0
Placunidae	*Placuna ephippium*	0.02	0	0	0	0.01	0.01	0.01	0	0	0
Spondylidae	*Spondylus sp.*	0	0	0	0	0	0	0.2	0	0	0
Tellinidae	*Scutarcopagia scobinata*	0	0	0	0	0	0	0.01	0	0	0
	Serratina sp.	0	0	0	0	0	0.02	0	0	0.09	0
Veneridae	*Gafrarium aequivocum*	0	0	0	0.44	0.18	0	0	0	0	0
	Gafrarium pectinatum	0	0	0	0	0	0	0	0.01	0.08	0
	Gafrarium tumidum	0.18	0.07	0.03	0	0	0.27	0.11	0	0	0
	Meretrix lyrata	0	0	0	0	0	0.05	0.01	0	0	0
	Paphia undulata	0	0.2	0	0	0	0	0	0	0	0
	Pitar sp.	0	0	0	0	0.08	0.08	0.01	0.01	0.05	0
	Tapes literatus	0	0	0	0	0.02	0	0	0	0.04	0

The most defining ecological feature of the bivalve assemblage is the high density of *Modiolus modulaides*. This species dominates areas with mixed rocky and muddy substrates, recording the highest overall density in Sinipay, Sibutad (3.458 ind/120 m^2) and Punta Sulong, Baliangao (2.842 ind/120 m^2). Significant assemblages were also found in other Sibutad sites like Canim (1.358 ind/120 m^2) and Panganuran (1.083 ind/120 m^2). The clumping nature of *M. modulaides* allows it to form dense colonies by anchoring its byssal threads to hard rocks embedded within softer mud. While this clumped distribution reduces overall species evenness in these specific sites, the complex physical matrix created by these species acts as a secondary micro-habitat for epifaunal organisms.

In contrast to that, the municipality of Rizal (Nangca and Nasipang) exhibited a highly specialized bivalve community driven by the presence of extensive seagrass beds. Nangca recorded the highest density of the commercially important *Anadara antiquata* (1.142 ind/120 m^2), while Nasipang supported the highest density of *Vasticardium flavum* (0.567 ind/120 m^2) and the exclusive presence of *Spondylus sp*. (0.200 ind/120 m^2).

The root-rhizome networks of seagrass meadows stabilize shifting sandy sediments and alter local hydrodynamic energy, creating an optimal environment for infaunal and semi- infaunal bivalves. This is strongly corroborated by Vian et al. (2022) and Mahilac et al. (2023), who demonstrated that the structural complexity of seagrass ecosystems in Southeast Asia serves as a critical refuge for families like Arcidae, Cardiidae, and Pinnidae. These taxa require firm anchorage in undisturbed, sandy-muddy sediments to maintain vertical orientation and maximize filter-feeding efficiency (del Norte-Campos et al., 2020).

The municipality of Sapang Dalaga, particularly the sites of Casul and Naputhaw, represents a fundamentally different ecological niche characterized by muddy substrates with high organic matter retention. Casul demonstrated significant densities of *Modiolus modulaides* (1.117 ind/120 m^2), alongside notable populations of *Gafrarium aequivocum* (0.442 ind/120 m^2) and *Anadara antiquata* (0.417 ind/120 m^2).

Muddy intertidal flats, due to their finer sediment fractions, function as highly productive feeding grounds for specific deposit and suspension feeders. Similar to the observations of Flores et al. (2014) in the mudflats of Banate Bay, Iloilo, the finer sediments in Sapang Dalaga favor species equipped to process high loads of particulate organic matter without clogging their ctenidia (gills). Furthermore, Sahidin et al. (2019) emphasize that stable, organic-rich muddy substrates consistently support higher localized densities of Veneridae (e.g., *Gafrarium* spp.) compared to highly turbulent or shifting sandy shores.

The data confirms that no single municipality holds all the biodiversity; rather, each site contributes a unique assemblage because of its substrate differences. While stable, rocky-muddy zones (Sibutad, Baliangao) support many individuals through generalist aggregations, seagrass beds (Rizal) and nutrient-rich mudflats (Sapang Dalaga) sustain niche-specific, commercially important species. Therefore, effective coastal management in the bay must adopt a localized, habitat-specific approach to protect these interconnected environments against anthropogenic degradation and over-gleaning (Kurniawan et al., 2024).

Diversity of Bivalves

The biodiversity status Bivalves in Murcielagos Bay, evaluated through the Shannon-Wiener (H') and Simpson's (*D*) diversity indices (Table 2), reveals a distinct ecosystem diversity influenced by municipal-specific habitat characteristics. The indices serve as indicators of community stability, where a higher H' value signifies a rich and evenly distributed community, while a Simpson's Index (*D*) closer to 1 indicates high diversity and a high probability that two randomly selected individuals belong to different species.

Table 6. *Shannon-Wiener Diversity Index (H') and Simpson's Diversity Index (D) of Bivalves in Murcielagos Bay.*

Municipality	**Bivalvia**	
	(H')	(*D*)
Sibutad	1.02	0.44
Rizal	1.99	0.81
Sapang Dalaga	1.82	0.80
Baliangao	0.89	0.34

As presented in Table 4, the highest bivalve diversity was recorded in Rizal (H' = 1.99; D = 0.81), followed closely by Sapang Dalaga (H' = 1.82; D = 0.80). In contrast, Sibutad (H' = 1.02; D = 0.44) and Baliangao (H' = 0.89; D = 0.34) exhibited noticeably lower diversity indices for.

The bivalve community in Rizal has moderate diversity indicating a relatively stable community structure where no single species excessively dominates. Similarly, the Simpson's Index suggests a high diversity status. This evenness in Rizal suggests an ecosystem capable of supporting multiple bivalve groups. Conversely, the bivalve communities in Sibutad and Baliangao has low diversity. The low index in Baliangao is driven by the abundance of *Modiolus modulaides*. While the total abundance is high, this massive aggregation lowers the evenness, resulting in low diversity values which signifies a community dominated by a few species.

Belduga and Galan (2021) noted that habitats with mixed substrates (sand-seagrass- rubble) often support richer bivalve assemblages compared to homogenous zones. The condition in Sapang Dalaga heavily influenced by the presence of *Gafrarium* species in muddy substrates, further corroborates Hamli et al. (2017), who identified venerid clams as dominant taxa in protected mudflats, contributing to moderate diversity levels.

In summary, the status of Bivalves in Murcielagos Bay ranges from Low to Moderate Diversity. The variation is substrate-dependent: heterogeneous seagrass beds (Rizal) promote moderate diversity and stability, while specific favorable substrates in Baliangao drive high dominance of single species, resulting in lower overall diversity indices.

Conservation Status

The conservation assessment of the benthic macroinvertebrate community in Murcielagos Bay reveals a significant information gap characteristic of tropical invertebrate datasets.

All 28 recorded species in this study are currently categorized as Not Evaluated (NE) by the IUCN (Table 5). While none are formally listed as threatened, the absence of assessment does not imply low risk. Instead, it highlights a significant knowledge gap in tropical marine invertebrate conservation. Moreover, 27 species are considered as commercially important according to del Norte-Campos et al. (2020).

Table 7. *Conservation status of Bivalves in Murcielagos Bay. Note: CS=Conservation Status, NE=Not Evaluated, LC=Least Concern, CI=Commercially Important*

Family	Species	CS	CI
Arcidae	*Anadara antiquata* (Linnaeus, 1758)	NE	✓
	Barbatia virescens (Reeve, 1844)	NE	✓
	Cucullaearca foliata (Forsskål, 1775)	NE	×
Cardiidae	*Fulvia mutica* (Reeve, 1844)	NE	✓
	Vasticardium angulatum (Lamarck, 1819)	NE	✓
	Vasticardium flavum (Linnaeus, 1758)	NE	✓
Glycymerididae	*Tucetona pectunculus* (Linnaeus, 1758)	NE	✓
Isognomonidae	*Isognomon isognomum* (Linnaeus, 1758)	NE	✓
Lucinidae	*Fimbria fimbriata* (Linnaeus, 1758)	NE	✓
Mactridae	*Spisula sachalinensis* (Schrenck, 1861)	NE	✓
Malleidae	*Malleus malleus* (Linnaeus, 1758)	NE	✓
Modiolidae	*Modiolus modulaides* (Röding, 1798)	NE	✓
Ostreidae	*Magallana bilineata* (Röding, 1798)	NE	✓
	Saccostrea echinata (Qouy & Gaimard, 1835)	NE	✓
Pinnidae	*Atrina pectinata* (Linnaeus, 1767)	NE	✓
	Pinna bicolor (Gmelin, 1791)	NE	✓
	Pinna muricata (Linnaeus, 1758)	NE	✓
Placunidae	*Placuna ephippium* (Philipsson, 1788)	NE	✓
Spondylidae	*Spondylus sp.*		✓
Tellinidae	*Scutarcopagia scobinata* (Linnaeus, 1758)	NE	✓
	Serratina sp.		✓
Veneridae	*Gafrarium aequivocum* (Holten, 1802)	NE	✓
	Gafrarium pectinatum (Linnaeus, 1758)	NE	✓
	Gafrarium tumidum (Röding, 1797)	NE	✓
	Meretrix lyrata (G. B. Sowerby II, 1851)	NE	✓
	Paphia undulata (Born, 1778)	NE	✓
	Pitar sp.		✓
	Tapes literatus (Linnaeus, 1758)	NE	✓

These bivalves serve as a primary livelihood, particularly for households in Sibutad, Rizal, Sapang Dalaga, and Baliangao, where gleaning provides both immediate food security and a supplementary income during lean fishing seasons. The high species richness within the family Veneridae and the localized dominance of species like *Modiolus modulaides* directly correlate with the dietary preferences and market demands of the region. However, while these species are vital to the local economy and traditional food systems, without formal conservation status or localized harvest regulations, the very resource that sustains these coastal livelihoods remains vulnerable to over-exploitation and habitat degradation. Consequently, protecting the taxonomic diversity of Murcielagos Bay is not merely an environmental priority but a socio-ecological necessity to ensure the long-term resilience of the fisheries and the nutritional autonomy of the bay.

The apparent absence of formally threatened species contrasts with the expected ecological profile of Philippine intertidal zones, which often face intense human utilization pressure. Studies across the Philippines consistently underscore the vulnerability of many molluskan taxa, particularly those targeted by fisheries or endemic species with restricted ranges. This leads to the Local Assessment Imperative, where the current data strongly highlights that relying solely on the global Red List is insufficient for effective conservation in Murcielagos Bay. Therefore, the conservation assessment for Murcielagos Bay must prioritize a localized conservation strategy focusing on population trend monitoring and the establishment of local protection levels for most of the unassessed species by the community and the LGUs.

Water Quality Parameters

The water quality of Murcielagos Bay was assessed to determine the influence of physico-chemical indices on the biodiversity and spatial distribution of Molluscs and Echinoderms. Parameters including temperature, pH, Total Dissolved Solids (TDS), salinity, and Dissolved Oxygen (DO) were measured across four municipalities and three intertidal zones. In highly dynamic ecosystems such as intertidal zones, organisms are subjected to fluctuating water quality parameters that act as physiological filters, dictating community structure and stability (Sahidin et al., 2019). The water quality in the bay was benchmarked against the standards set by the Department of Environment and Natural Resources (DENR) under Administrative Order (DAO) No. 2016-08 for Class SA and SB waters.

Table 8 presents the mean water quality parameters -Temperature, pH, Total Dissolved Solids (TDS), Salinity, and Dissolved Oxygen (DO) - across the four municipalities of Murcielagos Bay, including the standard deviation (*SD*) to illustrate environmental variance.

Table 8. *Summary of Water Quality Parameters by Municipality*

Municipality	Temp (°C)	pH	TDS (mg/L)	Salinity (ppt)	Dissolved Oxygen (DO) (mg/L)
Sibutad	29.08 ± 0.02	8.68 ± 0.59	21,359.49 ± 0.51	34.34 ± 1.34	5.13 ± 0.25
Rizal	29.32 ± 0.01	8.05 ± 0.01	30,409.27 ± 0.00	32.67 ± 0.00	5.20 ± 0.28
Sapang Dalaga	29.67 ± 0.01	8.15 ± 0.01	29,579.29 ± 0.00	32.67 ± 0.00	4.99 ± 0.01
Baliangao	28.78 ± 0.12	8.11 ± 0.19	24,939.40 ± 0.00	32.33 ± 0.01	5.00 ± 0.01

Note. Values are presented as Mean ± Standard Deviation (*SD*).

Mean surface water temperatures across Murcielagos Bay ranged from 28.78 ± 0.12 °C in Baliangao to 29.67 ± 0.01 °C in Sapang Dalaga. These values fall within the established thermal optima of 26.0 °C to 30.0 °C for tropical marine macrobenthos as mandated by DAO 2016-08 (DENR, 2016). However, the slight elevation in Sapang Dalaga appeared to be a selective filter, contributing to its lower diversity index (H' = 1.92) by favoring species with higher thermal plasticity. This aligns with findings by Wang et al. (2023), who noted that subtle thermal gradients can shift community composition toward generalist species. Conversely, the cooler and more stable thermal profile in Baliangao supports higher community stability and the persistence of specialized grazers like the Strombidae family. Stable temperatures prevent the competitive exclusion of sensitive species, maintaining higher values of diversity and evenness (Belduga & Galan, 2021).

The pH levels recorded across the bay were generally consistent with the DENR standard of 7.0 to 8.5, except for Sibutad, which recorded a slightly higher mean of 8.68 ± 0.59. This elevated alkalinity is particularly advantageous for calcifying organisms, as a higher carbonate saturation state reduces the metabolic energy required for the biocalcification of shells and tests (Byrne & Fitzer, 2019). The high density of *Modiolus modulaides* in Sibutad is likely supported by this favorable pH, which facilitates efficient mineral deposition (Byrne & Fitzer, 2019).

Total Dissolved Solids (TDS), serving as a proxy for dissolved minerals and nutrients, reached a peak in Rizal (30,409.27 ± 0.00 mg/L). This high concentration likely contributes to the productivity of Rizal's extensive seagrass meadows, which provide the complex niche architecture required to support the highest biodiversity recorded in this study (H' = 2.83). In contrast, the lower TDS in Sibutad (21,359.49 ± 0.51 mg/L) suggests a different nutrient dynamic, yet one that still supports high total density (N = 5,015) due to its rocky-sandy substrate.

Mean salinity values ranged from 32.33 ± 0.01 ppt in Baliangao to 34.34 ± 1.34 ppt in Sibutad, representing stable marine conditions within the optimal range of 28 to 35 ppt (Suckling et al., 2024). Sibutad's higher salinity reflects a more oceanic influence, which supports the massive aggregations of *Modiolus modulaides*. The relatively lower salinity and minimal variance in Rizal (32.67 ± 0.00 ppt) and Baliangao (32.33 ± 0.01 ppt) indicates a minor freshwater influence, yet it remains well within the tolerance levels of most marine macro-invertebrates (Arabaca et al., 2022). The Dissolved Oxygen (DO) levels in Murcielagos Bay ranged consistently from 4.99 ± 0.01 mg/L in Sapang Dalaga to 5.20 ± 0.28 mg/L in Rizal, generally meeting the minimum standard of 5.0 mg/L for Class SC waters (fishery and recreational use) set by the DENR (2016). These values indicate that the bay remains sufficiently oxygenated to support the respiration of the current benthic community; however, localized monitoring is necessary to ensure that DO levels do not dip further, which could impair the growth and reproduction of bivalves. Together, these physico-chemical parameters create a functional but stratified environment that governs the unique community structure observed across Murcielagos Bay.

Conclusion

The intertidal zones of Murcielagos Bay support a prominent but unevenly distributed bivalve community, comprising 28 distinct species across 14 families. The family Veneridae dominates the ecosystem, demonstrating high adaptability to the bay's varying sediment types, which range from sandy to muddy substrates. Overall, bivalve diversity within the bay ranges from low to moderate and is highly dependent on localized spatial and habitat characteristics. Heterogeneous environments, such as the mixed substrates found in Rizal, promote greater species richness, evenness, and overall community stability. Conversely, specific substrate conditions in areas like Baliangao allow for the monopolization of habitats by single species, notably *Modiolus modulaides*, which drives down overall diversity indices despite sustaining high total biomass. Furthermore, the widespread presence and dominance of specific suspension and deposit-feeding bivalves indicate that Murcielagos Bay is a highly productive ecosystem that is likely experiencing organic enrichment due to anthropogenic activities. Crucially, the assessment highlights a significant conservation gap, as all recorded species are classified as Not Evaluated (NE) by the IUCN, underscoring the insufficiency of global Red List data for local management. Consequently, there is an urgent need for localized conservation strategies specifically, it is recommended that the local government units (LGUs) establish or expand MPAs specifically in "biodiversity hotspots" identified in this study, such as in Rizal and Sibutad and regulation of gleaning and harvesting practices by establishment of "closed seasons" during peak spawning periods and the implementation of size-limit regulations to ensure that reproductive individuals are spared. Furthermore, continuous community-based monitoring and site-specific protection measures in partnership with the LGUs and the community to ensure the sustainable management of these economically and ecologically vital marine resources in Murcielagos Bay.

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Disclosure: Use of AI Tools

The author certifies that this work is original, has not been previously published, and is not under consideration elsewhere. To ensure academic integrity, the manuscript was subjected to formal plagiarism screening using Turnitin, yielding a similarity index that is within acceptable academic thresholds. While generative AI tools were utilized solely for language editing and manuscript refinement, the author maintains full responsibility for the fieldwork, data analysis, interpretation, and conclusions. Furthermore, the author declares no competing interests or conflicts of interest regarding the publication of this research.

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