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Diversity and community structure of seagrass at Arrecife Island, Honda Bay, Palawan, Philippines

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ABSTRACT

This study assessed the seagrass communities of Arrecife Island, Honda Bay, Palawan, Philippines, focusing on species composition, percent cover, and the diversity and density of associated macroinvertebrates, particularly sea cucumbers. Sampling was done on April 14-15, 2018, at daytime and low tide, using a transect-quadrat method in the established sampling sites. Percent cover was categorized using the dominance classification scheme, and diversity indices were computed to assess community structure. A total of five seagrass species were recorded, namely, *Cymodocea rotundata, Enhalus acoroides, Halodule uninervis, Syringodium isoetifolium,* and *Thalassia hemprichii*, as well as notable macroinvertebrates such as *Holothuria atra*. The results indicated that *T. hemprichii* was the most dominant species, significantly contributing to overall percent cover (59.73 ± 9.30). However, the overall seagrass bed in the area is classified as "fair" (25.5–50.4%). Seven macroinvertebrate species were recorded, with *Holothuria atra* exhibiting the highest population density (167 ind./250 m^2); diversity indices reflected moderate species diversity and evenness, with *H. atra* showing a dominant presence among sea cucumbers. These findings highlight the ecological significance of seagrass ecosystems in providing habitat and supporting biodiversity. However, ongoing threats like siltation, pollution, and tourism-related disturbances call for immediate conservation actions. Resort owners and employees are encouraged to participate in habitat protection actively. At the same time, periodic reassessments every five years are recommended to monitor ecological changes and guide conservation strategies. Such initiatives are critical for sustaining biodiversity, protecting ecosystem services, and promoting the well-being of local populations that rely on marine resources.

Keywords: Seagrass ecosystem, biodiversity, macroinvertebrates, marine conservation, sea cucumber

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INTRODUCTION

Seagrass ecosystems are integral to coastal environments, offering essential services supporting marine biodiversity, including humans (Paice and Chambers, 2016; Heckwolf et al., 2021; Kim et al., 2021). These specialized flowering plants, adapted to life in submerged aquatic habitats, are a critical component of shallow-water estuarine and marine ecosystems (Phang, 2000; McKenzie et al., 2006; Tanduyan et al., 2011; do Amaral Camara Lima et al., 2023). Seagrasses form extensive meadows that contribute to habitat complexity and coastal water health (Boström et al., 2006; Waycott et al., 2009; McKenzie et al., 2020, 2021; Unsworth et al., 2022). These meadows are particularly vital in tropical and temperate regions, serving as habitats for diverse marine species, including commercially valuable fish and endangered species (Duarte, 1999; Nordlund et al., 2017; Das et al., 2021; Fortes, 2022; Al-Mansoori and Das, 2024). The structural complexity of seagrasses provides refuge and food for juvenile organisms, supporting fish, invertebrates, and other species (Alima et al., 2014; Jiang et al., 2020). Seagrass beds are typically found in soft substrates, such as mudflats and sandy areas, and stretch 30 meters below the lower intertidal zone (Walker et al., 2010; McKenzie et al., 2021). These ecosystems stabilize sediments, produce oxygen, and sequester carbon, sustaining marine ecosystems (Walker et al., 2010; Heck et al., 2000; Fortes, 2022). Additionally, they enhance adjacent coral reef productivity through nutrient cycling (Waycott et al., 2009; Hughes et al., 2009; Tew et al., 2021). Seagrass beds are threatened by coastal degradation and climate change despite their ecological significance. These activities have accelerated the global decline of seagrass habitats, jeopardizing marine biodiversity and livelihoods (Duarte, 1999; Waycott et al., 2009; Howes et al., 2018; Exton et al., 2019; McKenzie et al., 2020, 2021; Priya et al., 2023). The loss of seagrass meadows negatively impacts fisheries, water quality, and coastal erosion, emphasizing the urgency of effective conservation strategies (Grech et al., 2011; McKenzie et al., 2020, 2021).

The ecological Interplay between seagrass, sea cucumbers, and other macroinvertebrates is fundamental to the functioning of seagrass ecosystems (Duarte, 1999; Floren et al., 2021). Seagrasses provide shelter, breeding grounds, and a rich source of food for various macroinvertebrates (Vinson et al., 2016; Capin et al., 2020). While macroinvertebrates play key roles in seagrass ecosystems, this study highlights the sea cucumber diversity due to their ecological importance in nutrient cycling and sediment bioturbation by feeding on organic matter in sediments, thereby improving sediment structure and enhancing seagrass bed health (Duarte, 1999; Jiang et al., 2020). In turn, this mutualistic interaction fosters the productivity of seagrass beds and supports marine biodiversity species dependent on these habitats (Sheaves et al., 2014; Waycott et al., 2009; Elkabbany, 2019). Further, studying macroinvertebrates in seagrass beds reveals trophic interactions, biodiversity patterns, and anthropogenic impacts like habitat loss and climate change (Liu et al., 2025). Understanding the structure of seagrass communities enhances our knowledge of the health and dynamics of seagrass ecosystems, particularly in underexplored areas like Arrecife Island in Honda Bay, Puerto Princesa City.

Thirteen seagrass species, or 27% of all species known to science, are found in the Philippines (Calumpong and Meñez, 1997; Fortes et al., 2018; Payo et al., 2018). While some seagrass ecosystems have been well-studied, many regions remain underexplored, suggesting the potential for discovering additional species. Tourism-related disturbances and the heavy exploitation of sea cucumbers in Honda Bay raise concerns about overexploitation, and the distribution and diversity of sea cucumbers remain limited (Jontila, 2023). Additionally, Honda Bay's status as a mercury hotspot further threatens local ecosystems, including the seagrass communities surrounding Arrecife Island (Bicera, 2009; Samaniego et al., 2024). Understanding the community structure of seagrass ecosystems in these less-studied areas is essential for gaining a deeper insight

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into their biodiversity and overall health. Although seagrass and macroinvertebrate ecosystems have received significant attention, research on sea cucumber populations in the Philippines is still limited (Schoppe, 2000; Quevedo et al., 2013; Dolorosa, 2015; Jontila et al., 2014, 2017, 2018). This study aims to fill critical knowledge gaps regarding the seagrass beds of Arrecife Island by examining species composition, percent cover, and macroinvertebrate density, with a particular focus on sea cucumbers. This research will strengthen the conservation and management of these vital coastal habitats by providing baseline data on sea cucumber populations and their interaction with seagrass ecosystems. The study's findings will inform local stakeholders and communities, enabling the development of more effective, sustainable conservation strategies to protect both seagrass and sea cucumber populations in Honda Bay.

MATERIALS AND METHODS

Description of the study area

Arrecife Island hosts an upscale resort in Honda Bay, a vital waterway and fishing destination east of Puerto Princesa City, Palawan, Philippines (Figure 1). The bay, situated near the West Sulu Sea, is characterized by barrier islets and sandbars that form a passive secondary shoreline (Dela Peña et al., 2017). Among the three bays surrounding the city, Honda Bay stands out for its relatively intact habitats, unlike other bays nationwide, including seagrass ecosystems (Roleda et al., 2001; Gonzales, 2004).

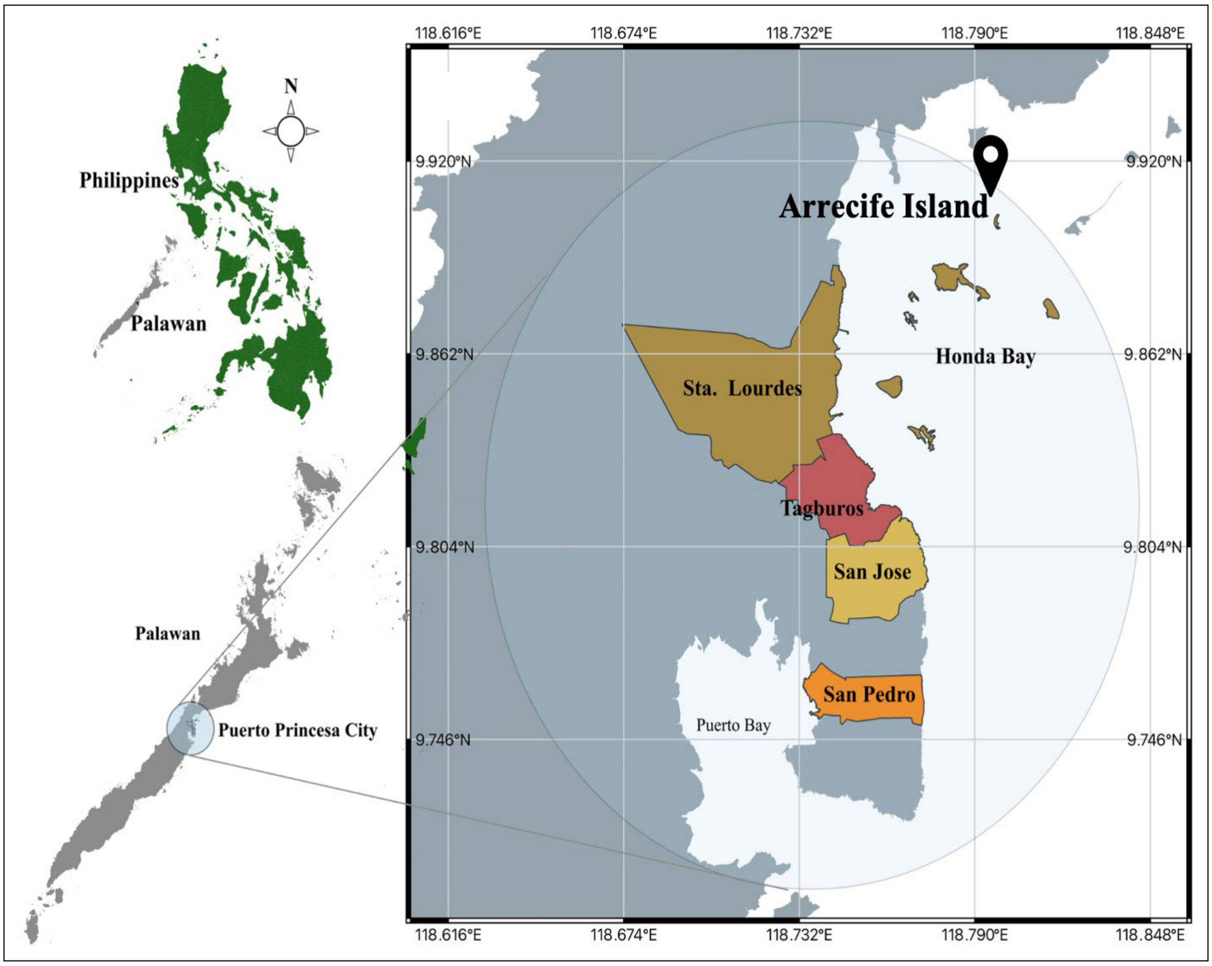

Figure 1. A map of Honda Bay with adjacent barangays and Arrecife Island is highlighted.

Sample collection

Field guides were used to identify the seagrass and macroinvertebrate species at the lowest taxonomic level (Meñez et al., 1983; Fortes, 1990, 2016; Dolorosa and Dangan-Galon, 2014; Dolorosa, 2015; Dolorosa et al., 2015; Jontila et al., 2014, 2017, 2018). Species names were standardized according to the World Register of Marine Species (WoRMS, 2024). Conservation statuses were determined using evaluations by the International Union for Conservation of Nature (IUCN, 2024) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES, 2024). The study was conducted on April 14-15, 2018, during daytime and at low tide. The length (cm) of the recorded macroinvertebrate species was also documented.

The shallow seagrass meadows around Arrecife Island were assessed using the transect-quadrat method outlined in English et al. (1994) and the Australia Institute of Marine Science (2004). Five transects, each 50 meters long and spaced 50 meters apart, were set up perpendicular to the beach, with 0.5 m × 0.5 m quadrats laid along the right side of the transect line, spaced five meters apart. The percent cover of each species within the quadrats was calculated using a scoring system adapted from Saito and Atobe (1970) and English et al. (1994). This non-destructive method avoids biomass removal and combines transect and quadrat techniques to map vegetation from intertidal to subtidal zones while quantifying species cover to determine distribution patterns.

The percentage cover of every seagrass species found in every quadrat was added to determine the relative percent cover for each transect (Capin et al., 2020). Seagrass cover conditions were categorized using Amra's (2010) five-point scale for coverage image: a scale of 5 with very good (>75.4%), 4 with good (50.5–75.4%), 3 with fair or rather reasonable (25.5–50.4%); 2 with bad (5.5–25.4%), and 1 with very bad (<5.5%).

Data analysis

Seagrass cover

To measure seagrass cover, a 0.5 m x 0.5 m quadrat with 25 sections (10 × 10 cm) wasused. Scales from 0 (no seagrass) to 5 (50–100% cover) were used in the dominance classification scheme. The midpoint value for each class was used to determine the species coverage) as (Saito and Atobe, 1970; Eq. 1):

$$C = \sum (M_i \times f) \quad \text{Eq. 1}$$

Where M_i is the midpoint percentage of class i and f is the number of sections in that class. The relative percent cover was calculated by dividing the total cover of each species by the total cover of all species, and then summing the total species cover in the site.

Macroinvertebrate density and diversity

To analyze the diversity of sea cucumber species in the seagrass communities of Arrecife Island, the diversity indices were calculated using data on species population density and occurrence. Species richness accounts for the total number of different species observed in the study area. The Shannon-Wiener Index (H') quantifies species diversity, accounting for both the abundance and evenness of sea cucumber species (Shanon, 1948; Eq. 2).

$$H' = -\sum_{i=1}^{S} p_i \ln(p_i) \quad \text{Eq. 2}$$

Where H' is the Shannon-Wiener Index of diversity; S stands for the total number of species; $p_i = \frac{n_i}{N}$ is the proportion of total population density contributed by sea cucumber species i; n_i is the total population density of sea cucumber species i; $N = \sum_{i=1}^{S} n_i$ is the total population density of all sea cucumber species combined; and ln (p_i) is the natural logarithm of the proportion p_i . The Maximum Shannon-Wiener Index (H_{max}) represents the hypothetical maximum diversity if all sea cucumber species were equally abundant (Shanon, 1948; Eq. 3).

$$H_{max} = \ln(S) \quad \text{Eq. 3}$$

Where H_{max} is the maximum diversity possible given the species richness; S is the total number of sea cucumber species; and ln is the natural logarithm function. The Pielou's Index (J') measures the evenness of sea cucumber species distribution and is calculated using Eq. 4 (Pielou, 1966).

$$J' = \frac{H'}{H_{max}} \quad \text{Eq. 4}$$

Where J' is the Pielou's Evenness Index; H' is the Shannon-Wiener Diversity Index; and H_{max} is the Maximum Shannon-Wiener Diversity Index. The Simpson's Dominance Index (D) reflects the dominance of a particular sea cucumber in the community (Simpson, 1949; Eq. 5).

$$D = \sum_{i=1}^{S} p_i^2 \quad \text{Eq. 5}$$

Where D represents for Simpson's Dominance Index; $p_i = \frac{n_i}{N}$ is the proportion of the total population density for sea cucumber species i; and S stands for the total number of sea cucumber species. Finally, for the Simpson's Index (1–D), the probability that two individuals randomly selected from a sample belong to different species was quantified (Simpson, 1949; Eq. 6).

$$1 - D = 1 - \sum_{i=1}^{S} p_i^2 \quad \text{Eq. 6}$$

Where 1-D is the Simpson's Index of Diversity; D represents for Simpson's Dominance Index; $p_i = \frac{n_i}{N}$ is the proportion of the total population density for sea cucumber species i; and S stands for the total number of sea cucumber species. All the analyses were done in R (R Core Team, 2024).

RESULTS

Species composition of seagrass

Twelve seagrass and macroinvertebrate species were recorded in the seagrass communities of Arrecife Island, Honda Bay, and Puerto Princesa City (Table 1). The surveyed seagrass belongs to the families Cymodoceaceae and Hydrocharitaceae. Within the established quadrats, five seagrass species were recorded: *Cymodocea rotundata, Enhalus acoroides, Halodule uninervis, Syringodium isoetifolium*, and *Thalassia hemprichii.* Additionally, *Oceana serrulata, Halodule pinifolia*, and *Halophila* minor were observed outside the quadrats (Figure 2). All identified seagrass species are classified as "Least Concern" on the IUCN Red List, with population trends ranging from stable to decreasing. The listed species were also not listed under CITES.

Table 1. List of the seagrass species identified in Arrecife Island, Honda Bay, Puerto Princesa City, along with their IUCN and CITES conservation status.

Family	Species	IUCN status (Population trend)	CITES status
Cymodoceaceae	*Cymodocea rotundata* Ascherson & Schweinfurth, 1870	Least concern (Stable)	Not listed
Hydrocharitaceae	*Enhalus acoroides* (Linnaeus f.) Royle, 1839	Least concern (Decreasing)	Not listed
Hydrocharitaceae	*Halodule uninervis* (Forsskål) Ascherson, 1882	Least concern (Stable)	Not listed
Cymodoceaceae	*Syringodium isoetifolium* (Ascherson) Dandy, 1939	Least concern (Stable)	Not listed
Hydrocharitaceae	*Thalassia hemprichii* (Ehrenberg) Ascherson, 1871	Least concern (Stable)	Not listed

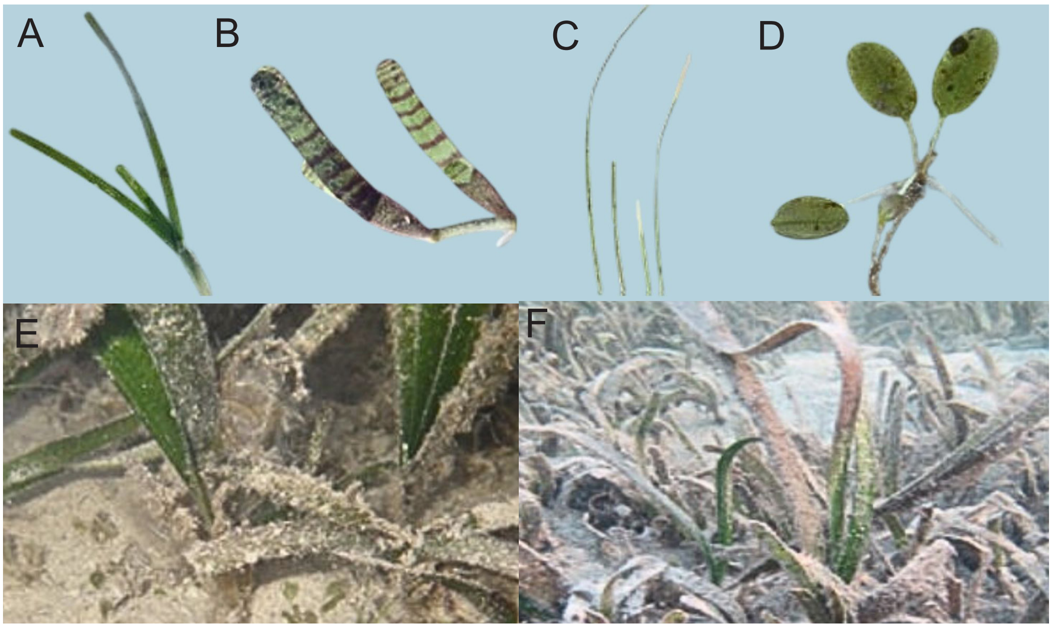

Figure 2. Seagrass species are found within and outside the established transect quadrats of Arrecife Island, Honda Bay, and Puerto Princesa City. *Cymodocea rotundata* (A), *Oceana serrulata* (B), *Halodule pinifolia* (C), *Halophila minor* (D), *Halophila* sp. (E), and *Enhalus acoroides and Thalassia hemprechii* (F).

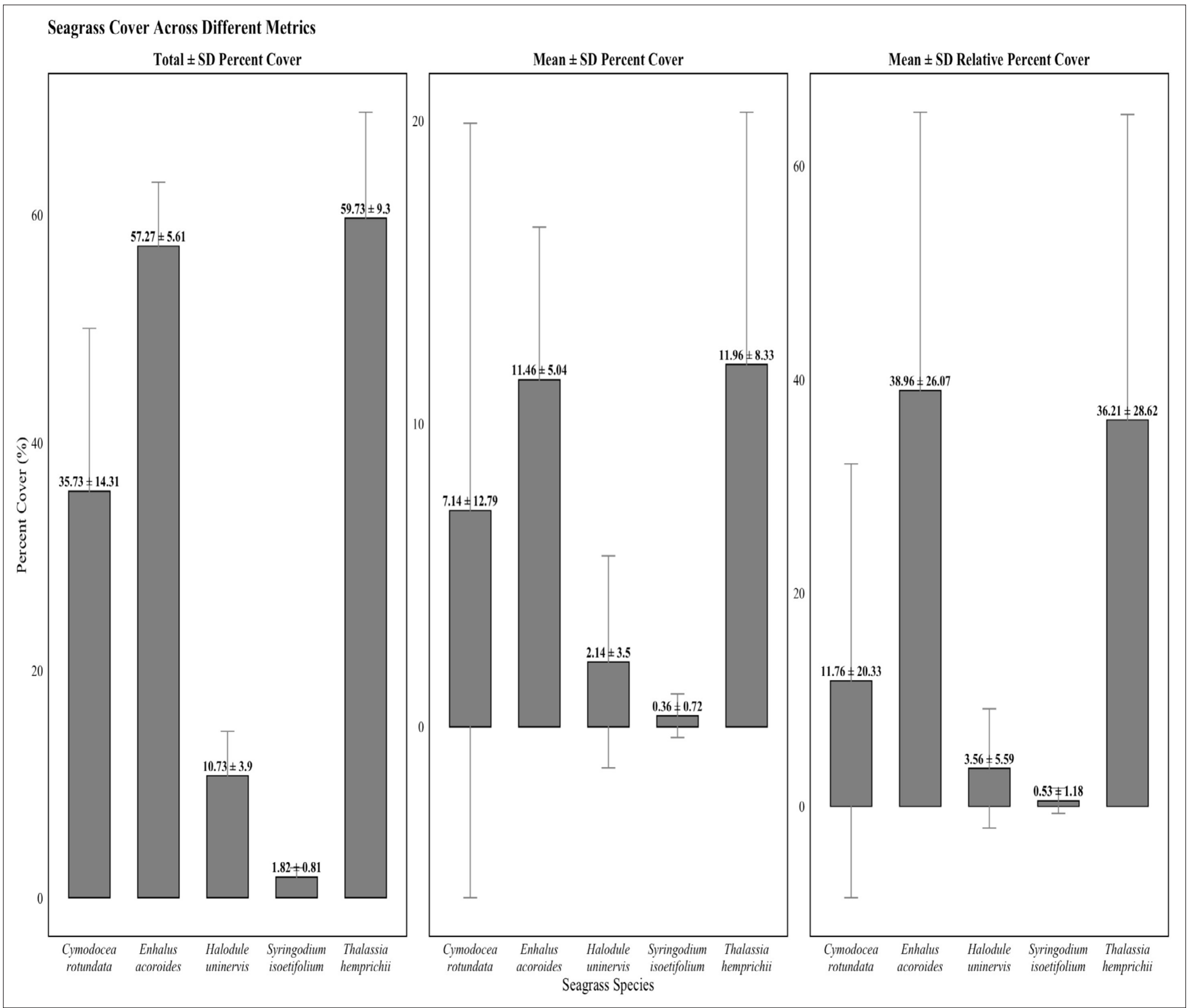

Figure 3. Seagrass coverage metrics in the seagrass communities of Arrecife Island, Honda Bay, and Puerto Princesa City.

Seagrass percent cover

The mean percent cover data categorizes the seagrass cover in "fair" conditions in the communities of Arrecife Island based on the scales proposed by Amran (2010). *Thalassia hemprichii* and *Enhalus acoroides* exhibited the highest total percent cover, with values of 59.73 ± 9.30% and 57.27 ± 5.61%, respectively (Figure 3). *Cymodocea rotundata* had a total percent cover of 35.73 ± 14.31%, while *Halodule uninervis* and *Syringodium isoetifolium* showed lower covers, with 10.73 ± 3.90% and 1.82 ± 0.81%, respectively.

For mean percent cover, *T. hemprichii* and *E. acoroides* also led with values of 11.96 ± 8.33% and 11.46 ± 5.04%, respectively. *Cymodocea rotundata* showed a moderate mean percent cover of 7.14 ± 12.79%, while *H. uninervis* and S. isoetifolium had lower mean percent covers of 2.14 ± 3.50% and 0.36 ± 0.72%, respectively, indicating a relatively sparse distribution of these species in the surveyed sites. The mean relative percent cover further underscores the dominance of *E. acoroides* and *T. hemprichii*, which accounted for 38.96 ± 26.07% and 36.21 ± 28.62% of the total seagrass coverage. These were followed by *C. rotundata* at 11.76 ± 20.33% and *H. uninervis* at 3.56 ± 5.59%. *Syringodium isoetifolium* recorded the lowest mean relative percent cover at 0.53 ± 1.18%, consistent with its limited overall presence. The frequency of occurrence data highlights the consistent presence of *T. hemprichii, E. acoroides, C. rotundata,* and *H. uninervis* across all surveyed sites, each achieving 100% frequency. In contrast, *S. isoetifolium* was observed in only 20% of the sites, indicating a highly localized distribution (Figure 3).

Macroinvertebrate composition characteristics

In total, seven macroinvertebrate species were identified, including four species of sea cucumbers: *Actinopyga lecanora, Bohadschia marmorata, Bohadschia vitiensis,* and *Holothuria atra*; two species of gastropods, *Cymbiola vespertilio* and *Cyprea tigris*; and one species of sea urchin: Tripneustes gratilla (Table 2, Figure 4). The macroinvertebrates are categorized within Actinopygidae, Stichopodidae, Holothuriidae, Cypraeidae, and Toxopneustidae.

Table 2. List of the macroinvertebrate species identified in Arrecife Island, Honda Bay, Puerto Princesa City, along with their IUCN and CITES conservation status.

Family	Species	IUCN status (Population Trend)	CITES status
Actinopygidae	*Actinopyga lecanora* Jaeger, 1833	Data deficient (Unknown)	Not listed
Stichopodidae	*Bohadschia marmorata* Jaeger, 1833	Data deficient (Decreasing)	Not listed
Stichopodidae	*Bohadschia vitiensis* Semper, 1868	Data deficient (Decreasing)	Not listed
Holothuriidae	*Holothuria atra* Jaeger, 1833	Least concern (Stable)	Not listed
Cypraeidae	*Cymbiola vespertilio* Linnaeus, 1758	Not evaluated	Not listed
Cypraeidae	*Cyprea tigris* Linnaeus, 1758	Not evaluated	Not listed
Toxopneustidae	*Tripneustes gratilla* Linnaeus, 1758	Not evaluated	Not listed

Among the sea cucumbers, three species (*A. lecanora, B. marmorata,* and *B. vitiensis*) are categorized as “Data deficient,” reflecting the lack of comprehensive population data. However, *H. atra* is listed as “Least c oncern” with a stable population trend. Notably, *B. marmorata* and *B. vitiensis* exhibit a decreasing population trend. The remaining macroinvertebrate species (*C. vespertilio, C. tigris,* and *T. gratilla*) have not yet been evaluated by the IUCN, and none of the species are listed under CITES, indicating they are not currently subject to international trade restrictions (Table 2).

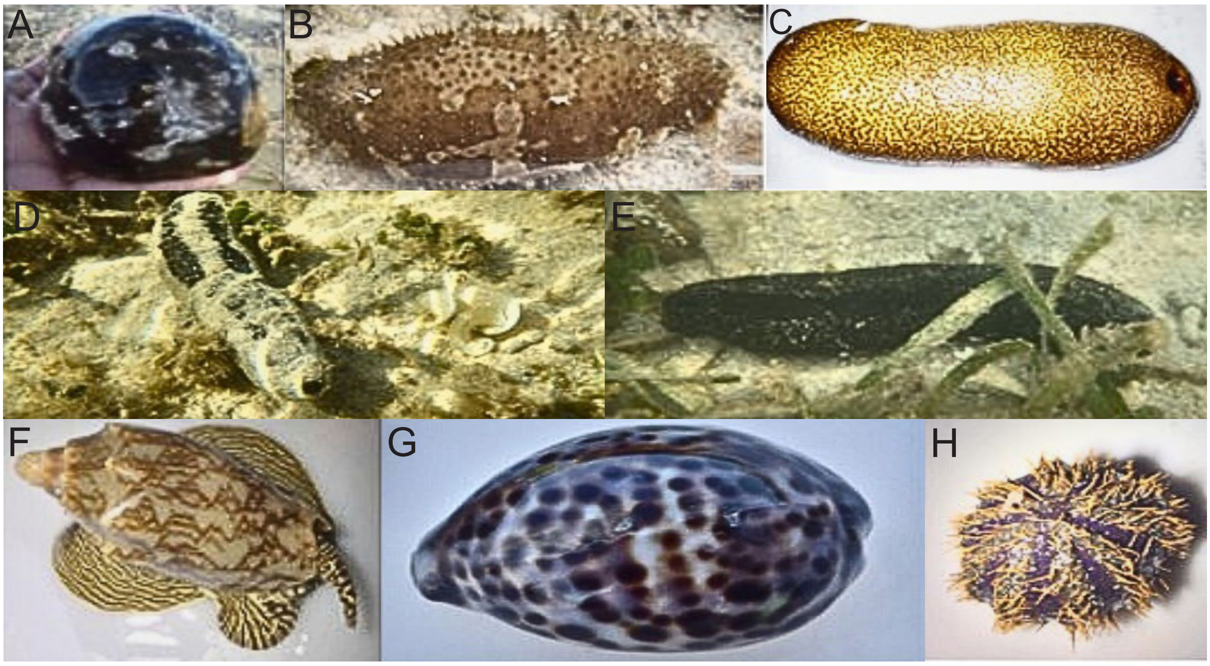

Figure 4. Macroinvertebrate species found during the transect quadrat survey in the established sampling site of the Arrecife Island, Honda Bay, Puerto Princesa City. *Actinopyga lecanora* (A), *Bohadschia marmorata* (juvenile) (B), *Bohadschia vitiensis* (C), *Holothuria atra* (D, E), *Cymbiola vespertilio* (F), *Cypraea tigris* (G), and *Tripneustes gratilla* (H).

Table 3. Population characteristics of macroinvertebrates in the seagrass communities of Arrecife Island, Honda Bay, Puerto Princesa City.

Class	Species	TPD (ind./ 250 m²)	Mean ± SD PD (ind./ 250 m²)	n	Mean ± SD L (cm)	Min. L (cm)	Max. L (cm)	FO (%)	DI (%)
Holothuroidea	*Actinopyga lecanora*	5	3.33	5	10.33 ± 0.57	10	11	20	2.16
	Bohadschia marmorata	23	23	69	17.41 ± 4.05	7	26	100	9.96
	Bohadschia vitiensis	1	0.33	1	-	36	36	20	0.43
	Holothuria atra	167	55.66	167	16.85 ± 5.08	4	33	100	72.38
Gastropoda	*Cymbiola vespertilio*	5	1.66	5	7.00 ± 0.61	6.5	8	20	2.16
	Cypraea tigris	25	8	24	6.74 ± 0.95	5	10	80	10.82
Echinoidea	*Tripneustes gratilla*	5	1.66	5	10.6 ± 0.89	10	12	20	2.16

TPD: Total Population Density (ind./250 m²); Mean ± SD PD: Mean ± Standard Deviation Population Density (ind./250 m²); n: sample size; Mean ± SD L: Mean ± Standard Deviation Length (cm); Min. L: Minimum Length (cm); Max. L: Maximum Length (cm); FO: Frequency of Occurrence (%); DI: Dominance Index (%)

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The macroinvertebrate community at Arrecife Island is dominated by *H. atra,* with a total population density of 167 individuals per 250 m², significantly higher than all other recorded species. This corresponds to a mean ± SD density of 55.66 ± 5.08 individuals per 250 m² (Table 3). *Bohadschia marmorata* exhibited the second-highest density, with 23 individuals per 2250 m² and a mean of 23 individuals per 250 m². *Cypraea tigris* followed with a total density of 25 individuals per 250 m² and a mean of 8 individuals per 250 m². In contrast, species such as *A. lecanora, T. gratilla,* and *C. vespertilio* had low densities (5 individuals each), while *B. vitiensis* had the lowest density, with only one individual per 250 m², reflecting its rarity.

The length measurements among species show substantial variability. Bohadschia vitiensis exhibited the longest recorded individual at 36 cm, while *H. atra* included the smallest individual at 4 cm, indicating a broad size range within this species. On average, *B. marmorata* was the largest, with a mean length of 17.41 ± 4.05 cm, followed closely by *H. atra* at 16.85 ± 5.08 cm. *C. vespertilio* and *C. tigris* were among the smallest species, with average lengths of 7.00 ± 0.61 cm and 6.74 ± 0.95 cm, respectively.

Species occurrence varied significantly across the surveyed area. *Holothuria atra* and *B. marmorata* were ubiquitous, occurring in 100% of the sampled quadrats, suggesting their ecological importance. *Cypraea tigris* had a high occurrence of 80%, indicating its broad distribution within the area. However, species such as *A. lecanora, B. vitiensis, C. vespertilio,* and *T. gratilla* were less frequent, each recorded in only 20% of the quadrats, suggesting a more localized or limited presence.

Similarly, *H. atra* overwhelmingly dominated the macroinvertebrate community with a dominance index of 72.38%, reflecting its ecological prevalence in the seagrass habitat. *Cypraea tigris* and *B. marmorata* contributed moderately, with dominance indices of 10.82% and 9.96%, respectively. Other species, such as *A. lecanora, C. vespertilio, and T. gratilla,* showed minimal contributions, with dominance indices of just 2.16% each. Bohadschia vitiensis exhibited the lowest dominance at 0.43%, emphasizing its rarity.

Diversity indices of sea cucumber species

The species richness (*S*) of sea cucumbers in the seagrass communities was recorded as 4, reflecting the number of different sea cucumber species present in the area and indicating moderate species diversity in Arrecife Island (Table 4). The Shannon-Wiener diversity index (H') for the sea cucumber population was calculated to be 0.58. This relatively low value suggests a community dominated by a few species, consistent with the high prevalence of *H. atra*. The maximum diversity (H_{max}) was determined to be 1.39, representing the theoretical diversity if all species were equally abundant. The notable discrepancy between H' and H_{max} highlights the uneven distribution of species within the sea cucumber community.

Table 4. Diversity indices of sea cucumber species in the seagrass communities of Arrecife Island, Honda Bay, Puerto Princesa City.

Indices	Values
Species richness (*S*)	4
Shannon-Wiener Index (H')	0.58
H_{max}	1.39
Pielou's Index of Evenness (J')	0.42
Simpson's Index of Diversity ($1 - D$)	0.26
Simpson's Dominance Index (D)	0.74

The evenness index (*J'*) was 0.42, further highlighting the uneven abundance of sea cucumber species. This finding supports the observation that particular species, such as *H. atra*, are overwhelmingly dominant, whereas others, such as *B. vitiensis*, are in much lower numbers. The Simpson's Index of Diversity (1 − *D*) was recorded at 0.26, providing additional evidence of low diversity within the community. This value indicates that a small number of species contribute to most observed individuals. Conversely, the Simpson's Dominance Index (*D*) was 0.74, clearly illustrating the overwhelming dominance of *H. atra* in the surveyed area.

DISCUSSION

Seagrass biodiversity and conservation challenges

The Philippines hosts 18 recognized species of seagrass (Fortes, 2013), with Arrecife Island alone accounting for 54% of this diversity. This remarkable biodiversity is exemplified by seven seagrass species recorded in the area. Within the surveyed transects, the species recorded *C. rotundata, E. acoroides, H. uninervis, S. isoetifolium,* and *T. hemprichii.* An additional three species, *C. serrulata, H. pinifolia,* and *H. minor*, were noted outside the transects but within the vicinity. Previous research by Gonzales (2004) identified eight species, and the unpublished studies by Jontila et al. emphasized the presence of *S. isoetifolium* and *H. pinifolia*, bringing the total to eight species in Arrecife Island—approximately 62% of the seagrass species recorded nationwide (Figure 2). Seagrass diversity was not assessed in this study; however, the eight recorded species fall below the threshold of 10 species typically observed in healthy meadows (Alcala et al., 2008), which remains significant given the island's small size within Honda Bay, Puerto Princesa City. The absence of certain species in the transects might reflect sampling limitations during a single visit. Environmental factors, such as substrate type, significantly influence seagrass distribution. In this study area, the substrate primarily consists of sandy to muddy sediments (Gonzales, 2004), which may favor certain seagrass species while limiting others (Lamit and Tanaka, 2019). Meode et al. (2014) emphasized that substratum characteristics are pivotal in regulating seagrass growth, while Wahab et al. (2017) argued that biotic interactions, including predation, further shape species distributions. Variations in macroinvertebrate populations across the island suggest a complex interplay of ecological factors within this seagrass ecosystem.

Arrecife Island's seagrass meadows, surrounded by expansive beds, host high densities of associated species, such as sea cucumbers, particularly in undisturbed areas. In contrast, nearby sites with open access to gleaning and fishing face significant declines in sea cucumber populations, highlighting the role of protection from exploitation in sustaining seagrass-associated biodiversity (Gonzales, 2004). According to Amran's (2010) classification, Arrecife Island's seagrass beds are rated as "fair" (25.5–50.4%), with *T. hemprichii* (59.73±9.30%), *E. acoroides* (57.27±5.61%), and *C. rotundata* (36.73± 14.31%) as the most abundant species. The dominance of *T. hemprichii, E. acoroides*, and *C. rotundata* in the Philippines is attributed to their adaptability to varied substrate types, efficient clonal growth, and tolerance to environmental stressors, allowing them to outcompete other species (Arriesgado et al., 2023). Their ability to stabilize sediments, trap nutrients, and support diverse marine life further reinforces their ecological success (Shen et al., 2023). These findings align with observations in other Philippine regions, such as Hagonoy, Davao del Sur (Jumawan et al., 2015; Noel et al., 2012), and Zambales (Paz-Alberto et al., 2015). Similarly, Gonzales (2004) noted the dominance of *E. acoroides* in local waters, while *T. hemprichii* exhibited the highest shoot density. Currently, no published studies on seagrass

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research are available for the study area. Therefore, the comparison of the most recent data can only be made with the work of Gonzales (2004).

Anthropogenic pressures, including siltation and pollution, pose significant threats to Honda Bay's seagrass ecosystems. Industrial and domestic waste from Puerto Princesa City flows into the bay via eight rivers, delivering organic and inorganic pollutants that degrade coastal resources (Gonzales, 2004; Bicera, 2009). Past mining activities have further exacerbated these impacts. Fortes et al. (2016) and Lan et al. (2024) warned that coastal developments, such as reclamation and dredging, disrupt water flow and accelerate ecosystem degradation through eutrophication, algal blooms, and increased turbidity. Despite Arrecife Island's private ownership providing some protection, its coastal resources remain vulnerable to tourism-related disturbances. Gonzales (2004) documented resource-use conflicts linked to tourism activities in Honda Bay, though these pressures temporarily subsided during the COVID-19 pandemic (2020–2021). Nevertheless, a survey by Dela Peña (2017) revealed a slight decline in public perception of the seagrass bed's condition, underscoring the need for more robust conservation measures.

The patterns observed in Arrecife Island mirror typical seagrass beds in the Philippines and other Asian regions characterized by sandy-muddy-coral rubble substrates (Capin et al., 2020). These meadows play vital ecological roles, including sediment stabilization and wave energy reduction, which are increasingly critical amid climate change and rising sea levels (Christianen et al., 2013; Unsworth et al., 2018). Anthropogenic disturbances threaten seagrass environments worldwide, including pollution, habitat degradation, and agricultural runoff. These disturbances lead to eutrophication and algal blooms, which harm seagrass health (Polidoro et al., 2017; McMahon et al., 2022).

Seagrass ecosystem conservation necessitates targeted strategies, including marine protected areas, regulated fishing practices, and public education campaigns to raise awareness of their ecological importance. Integrating scientific research with community involvement can enhance conservation efforts, fostering local stewardship of these critical habitats (Grech and Coles, 2010; Polidoro et al., 2012; Rifai et al., 2024). As one of Earth's most productive ecosystems, seagrass beds promote biodiversity and sequester carbon, among other ecological functions (Losciale, 2024). However, their ongoing decrease emphasizes the need to implement comprehensive management strategies that balance sustainable resource use and environmental preservation (Maxwell et al., 2015; Warnell et al., 2022).

Macroinvertebrate population at Arrecife Island

Jontila et al. (2014) reported that Palawan hosts 44 species of sea cucumbers but noted that in seagrass beds with sandy-muddy bottoms, *H. atra* is less prevalent. Despite this, the dominance of *H. atra* at Arrecife Island highlights the critical role of keystone species in maintaining ecosystem health. As a detritivore, *H. atra* is crucial in nutrient cycling by consuming organic matter and promoting sediment turnover, enhancing nutrient availability for other species, and supporting overall biodiversity (Silva and Henry, 2017; Gleason et al., 2022). Its significant presence (72.38%) among macroinvertebrates highlights its adaptability to environmental changes such as seasonal variations and nutrient fluctuations (Wang et al., 2020). However, this study's single-visit limitation prevents conclusions about seasonal patterns. The adaptability of *H. atra* is critical for ecological resilience—an ecosystem's ability to absorb disturbances while maintaining structure and function (Farooq et al., 2021). In dynamic seagrass ecosystems, where environmental conditions fluctuate due to nutrient loading, sedimentation, and climate change, resilient species like *H. atra* are vital for stability (Björk et al., 2008; Congdon et al., 2023).

The presence of B. marmorata, the second most abundant species, further highlights the importance of detritivores in ecosystem functioning (Gleason et al., 2022). Its even distribution across quadrats suggests a significant role in organic matter decomposition, creating conditions that enhance biodiversity. Multiple detritivores, such as *H. atra* and *B. marmorata*, optimize nutrient cycling by exploiting different aspects of organic matter, improving decomposition efficiency (Blaen et al., 2013). This interspecies cooperation is essential for nutrient-poor seagrass habitats (Valdez et al., 2020). Though less abundant, specialized species like C. tigris also contribute uniquely to the ecosystem. Its high occurrence (found in 80% of quadrats) indicates a specialized ecological niche, supporting theories that emphasize the role of habitat diversity in fostering biodiversity through microhabitat specialization (Mondy and Schuwirth, 2017). Such niche partitioning stabilizes communities, enabling ecosystems to withstand environmental fluctuations (Stachowicz et al., 2007). Even species with low densities, such as *A. lecanora*, *C. vespertilio*, and *T. gratilla*, form a vital component of specific interactions, enhancing seagrass community resilience (Hooper et al., 2005).

The limited occurrence of certain species (<20% of quadrats) may be indicative of their vulnerability to ecological stressors like habitat degradation, competition, or predation (Rodil et al., 2012; McGoff et al., 2013). This underlines the importance of targeted conservation strategies to support vulnerable species and maintain ecosystem resilience. While Arrecife Island's privately owned seagrass beds have been shielded from overexploitation, tourism-related activities may have influenced the distribution of species in the area.

The hierarchical structure of Arrecife Island's macroinvertebrate community, dominated by *H. atra and B. marmorata*, aligns with ecological theories emphasizing keystone species in ecosystem stability. These species are crucial for nutrient cycling, habitat structuring, and interspecies interactions, which help stabilize the ecosystem (Wang et al., 2023). The vulnerability of less abundant species highlights the intricate ecological interactions shaping community dynamics. Rising sea temperatures, ocean acidification, and changed nutrient dynamics are only a few of the major issues that climate change poses to seagrass ecosystems, and they may impact species abundance and distribution (Doney et al., 2020). Understanding these responses is critical for predicting the future of seagrass ecosystems and their biodiversity (Asante et al., 2023). Resilient species like *H. atra* are likely to significantly contribute to maintaining ecosystem resilience amid these challenges (O'Leary et al., 2017).

Sea cucumber diversity of Arrecife Island

The assessment of sea cucumber diversity within the seagrass communities of Arrecife Island looks at the ecological dynamics and biodiversity of this marine habitat. Sea cucumbers are important for nutrient cycling and sediment bioturbation, which are essential for the environmental functioning of seagrass ecosystems (Floren et al., 2021). The species richness (S = 4) observed in this study reflects a moderate level of diversity, suggesting that while multiple species are present, dominance by a few key species, particularly *H. atra*, significantly skews the overall community structure. This is consistent with findings by Vijayakumari et al. (2018) and Morris et al. (2014), who highlight the dominance of a few species as a typical pattern in tropical and subtropical benthic environments.

The Shannon-Wiener diversity index (H' = 0.58) indicates relatively low diversity, which aligns with the ecological principle that low H' values

(<1.0) signify uneven distribution and dominance of particular species (Morris et al., 2014; Ghazi-Yaker, 2023). This value highlights the influence of *H. atra* on the overall community structure. The potential for diversity, as indicated by the maximum diversity (H_{max} = 1.3863), suggests that the habitat can support a more balanced community. However, H_{max} varies between communities and depends on species richness (Shannon, 1948). The dominance of *H. atra*, however, is corroborated by the Simpson's Dominance Index (D = 0.74), which suggests that environmental conditions or ecological pressures may favor the prevalence of this species (Vijayakumari et al., 2018).

Pielou's Evenness Index (J' = 0.42) reinforces the uneven distribution pattern. Values below 0.5 indicate that one or a few species are disproportionately represented (Pielou, 1966), as seen in similar studies where dominance by a single species reduced community evenness and ecological resilience (Morris et al., 2014; Ma and Ellison, 2018). The Simpson's Index of Diversity ($1 - D$ = 0.2) further supports this observation, highlighting the seagrass habitat's limited diversity and potential vulnerability to disturbances. Such dominance reduces the overall functional redundancy of the ecosystem, which can affect its ability to recover from perturbations (Lalonde and Ernst, 2012).

The low species evenness and diversity indices point to potential ecological imbalances arising from anthropogenic pressures, habitat degradation, or natural factors (Karrouch et al., 2017). For instance, studies have documented that low evenness in marine communities is often linked to overfishing, eutrophication, and habitat fragmentation (Johnston and Roberts, 2009; Jessen et al., 2013; Morris et al., 2014). Dominance by *H. atra* may also indicate environmental conditions such as sediment composition, organic matter content, or water quality parameters that selectively favor this species (Lalonde and Ernst, 2012). Moreover, low biodiversity in seagrass ecosystems can have cascading effects on ecological functions (Unsworth and Cullen-Unsworth, 2014). Studies by Lalonde and Ernst (2012) and Morris et al. (2014) suggest that communities with low diversity are less resilient to environmental changes, making them more susceptible to regime shifts.

Comparative studies in similar habitats have shown that higher species richness and evenness are crucial for maintaining ecosystem stability and productivity. For example, research in tropical wetlands and marine reserves has demonstrated that diverse communities are better equipped to buffer against environmental disturbances and provide critical ecosystem services (Vijayakumari et al., 2018). The dominance of *H. atra* at Arrecife Island's seagrass beds may reflect natural competitive hierarchies and anthropogenic influences such as nutrient loading or physical habitat alteration. The relatively low diversity observed may also result from sampling biases or temporal fluctuations in community structure. The population dynamics of sea cucumber species may be impacted by local environmental factors, recruitment cycles, and seasonal variations—all of which were not considered in this study. Future studies should incorporate long-term monitoring and broader spatial sampling to capture a more comprehensive picture of community dynamics.

CONCLUSION

The assessment of seagrass communities in Arrecife Island, Honda Bay, highlights this marine habitat's ecological importance and biodiversity. With five seagrass species and seven macroinvertebrate species recorded, the area serves as a vital refuge for marine life. Seagrass species such as *T. hemprichii* and *E. acoroides* thrive with "fair" cover conditions. In contrast, others, like *S. isoetifolium*, are far less prevalent, indicating variations in their contributions to the ecosystem. Among the macroinvertebrates, *H. atra* dominates the population in density and distribution, whereas others, such as *B. vitiensis*, are scarce, pointing to ecological imbalances. Biodiversity indices of sea cucumbers reveal moderate species richness but a lack of even distribution, driven by the overwhelming presence of a few species. These findings reflect the critical need for conservation efforts to protect both the dominant and vulnerable species, ensuring the health and resilience of this marine ecosystem. Protecting Arrecife Island's seagrass communities is essential for preserving their ecological role and securing the future of Honda Bay's diverse marine life.

RECOMMENDATIONS

Regular reassessments every five years are crucial to monitor changes and guide conservation efforts to ensure the long-term health and sustainability of Arrecife Island's seagrass communities and associated biodiversity. Protection should prioritize maintaining dominant species like *T. hemprichii* while supporting less prevalent ones like *S. isoetifolium*. Managing ecological imbalances, particularly the dominance of *H. atra*, and enhancing vulnerable species populations is essential. Resort owners and their employees should lead as local stewards, adopting sustainable practices and promoting habitat preservation. Strengthening Marine Protected Areas, rehabilitating degraded habitats, and integrating scientific research into policy development will further enhance the resilience of this vital ecosystem against climate change and other threats.

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AUTHOR CONTRIBUTIONS

CBC: Conceptualization, Methodology, Data Analysis and Visualization, Writing—Final draft preparation; JBSJ: Data curation, Methodology, Supervision, Data Collection, Investigation, Writing—Original draft, Review and Editing, Funding Acquisition, Validation; MLEP: Conceptuaization, Data Collection, Writing—Reviewing and Editing, Validation.

CONFLICT OF INTEREST

The authors of this research affirm that they have no conflicts of interest.

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