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Research Article

Brachyuran Crab Diversity in the Mangrove Rehabilitation Site of Misamis Oriental, Mindanao Island, Philippines

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ABSTRACT
This study was conducted to determine the crab diversity of the mangrove rehabilitation site in Misamis Oriental, Mindanao, Philippines. Specifically, it aimed to (1) determine the species composition of crabs in the mangrove area; (2) assess the species richness, relative abundance, and density of crab species; (3) evaluate the species diversity of crabs, and; (4) compare the diversity of crab species found in the mangrove area. Three sampling sites were selected using a plot sampling technique. A total of 163 individuals in 12 species of brachyuran crabs from seven families were recorded at the site. In terms of relative abundance, station 3 (Eastward zone) had the highest abundance with 93 individuals, followed by station 1 (Landward zone) with 47 individuals, and station 2 (Middle zone) with 21 individuals. *Mictyris longicarpus* had the highest population density of 0.12 individuals/m^2, while *Ptychognathus* sp. and *Portunus reticulatus* had the lowest population density of 0.01 individuals/m^2. The Shannon-Weiner diversity index revealed that sampling station 3 (Eastward zone) had the highest diversity index of H' = 1.77 compared to stations 1 (H' = 1.70) and 2 (H' = 1.42). The key finding of this study showed that brachyuran crab species were more abundant and diverse in the zonation of new-growth mangroves compared to the old-growth mangroves.

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INTRODUCTION

One of the most productive and bio-culturally important marine ecosystems on Earth is the mangrove forest (Gong et al. 2019; Buenavista & Purnobasuki 2023). Amongst the ecologically and economically important components of mangrove forests are the crabs, which are divided into two types: brachyuran crabs (infraorder Brachyura) and anomuran crabs (infraorder Anomura). Crabs and other members of the taxonomic group Decapoda, such as lobster and shrimp, are important in commercial fisheries (Vergel 2017). Mud crab culture was introduced in the Philippines to provide an alternative source of income for fishermen in rural villages (Yasmin 2018). Mangrove crabs are a mainstay of the Philippines' seafood industry, generating approximately 94.5 million U.S. dollars per year (Pecl et al. 2017). However, despite their importance, mangroves and the various economically and ecologically important marine resources are being degraded and rapidly disappearing. In Mindanao Island, for example, mangrove forests face threats from garbage dumping, tree cutting, boat mooring, and human encroachment (Sitoy & Buenavista, 2024). In fact, the decline of mangrove forest cover continues in many parts of the world, particularly in Southeast Asia, where the Philippines tops the list of "mangrove loss hotspots" (Friess et al. 2019; Gandhi & Jones 2019; Bhowmik et al. 2022). One of the mangrove reforestation projects in Mindanao, Philippines, can be found in Barangay Pangayawan, Municipality of Gitagum, Misamis Oriental, Philippines. The site was previously home to native mangrove species *Sonneratia alba* (J. Smith), but the area was not protected at the time, and some mangroves were cut down for lumber and other purposes. As a result, the local government of Gitagum, in collaboration with the Department of Environment and Natural Resources (DENR), Bureau of Fisheries and Aquatic Resources (BFAR), Philippine Coast Guard (PCG), and the Misamis Oriental Provincial Government, embarked on a joint project to rehabilitate the 4-hectare mangrove area in 2015.

Protected mangrove ecosystems can provide important ecosystem services to coastal communities, including tangible benefits such as recreation and intangible benefits such as aesthetic appeal and spiritual values. Additionally, they can adapt to climatic changes and serve as platforms for educating others on the importance of mangrove protection and rehabilitation. Mangrove restoration projects are designed to be experiments that can be used as case studies and more general models to guide future restoration efforts. The Barangay Pangayawan mangrove rehabilitation project was found to be effective in promoting local mangrove conservation. Given the positive outcome of the project, it becomes extremely important to the residents of Gitagum. Evidently, the project resulted in the prohibition of dynamite fishing, which is partly credited to the group's prominence, and the participation of fishermen who are now defending the mangrove (Taneo & Areola 2022). Although the mangrove forest or mangal provides various ecosystem services (ES) in the area, its provisioning ecosystem services (PES), in particular, the economically important marine resources like crabs remain undervalued and understudied. As such, this research was carried out to evaluate the brachyuran crab assemblage and diversity in old-growth and new-growth mangrove forests.

MATERIALS AND METHODS

Entry Protocol and Ethical Considerations

Following the ethical guidelines of Central Mindanao University, prior informed consent (PIC) was obtained from the Barangay Captain of Barangay Pangayawan and the Office of the Municipal Mayor of Gitagum, Misamis Oriental. Wildlife Gratuitous Permit No. R10 2023-30 was used for the legal and authorized collection of voucher specimens in compliance with Republic Act 9147 of 2001 (Government of Philippines 2001).

Place and Duration of the Study

The Mangrove Rehabilitation Site is located in Barangay Pangayawan, Gitagum, Misamis Oriental, Mindanao, Philippines (Figure 1). The site is geographically located at 8° 35' 59.99" N 124° 23' 59.99" E, with an elevation of 129.0 meters (423.2 feet) above sea level. The town, locally known as barangay, has an estimated population of 17,920 residents (Mapa 2020), and based on the Annual Audit Report of the Municipality of Gitagum (2015), one of its primary sources of income is fishing and farming. The municipality of Gitagum extends for approximately 6.2 kilometers along the shore of the Mindanao Sea. The four-hectare mangrove area in Gitagum has been described as an important habitat and an ideal breeding ground for many marine animals (Rajpar & Zakaria 2013; Taneo & Areola 2022). The mangroves that can be found in Gitagum are composed of *Avicennia marina* (Forsk) Vierh. (commonly known as Bungalon, Api Api, Miapi), *Sonneratia alba* Sm. (commonly known as Pagatpat), *Lumnitzera racemose* Wiild. (commonly known as Tabao, Culasi), *Rhizophora apiculata* Blume (commonly known as Bakhaw Lalaki), *Rhizophora mucronata* var. alokii (commonly known as Bakhaw Babae), and *Nypa fruticans* Wurmb. (commonly known as Nipa). These species are among the mangroves present in the area. The study was conducted over five months, from October 2022 to March 2023.

Sampling Procedure

Establishment of Sampling Stations

The study site was divided into three sampling stations (Figure 1). The sampling stations were identified based on the presence and zonation of the mangrove community in the area. In each sampling station, one (1) 10 m x 10 m

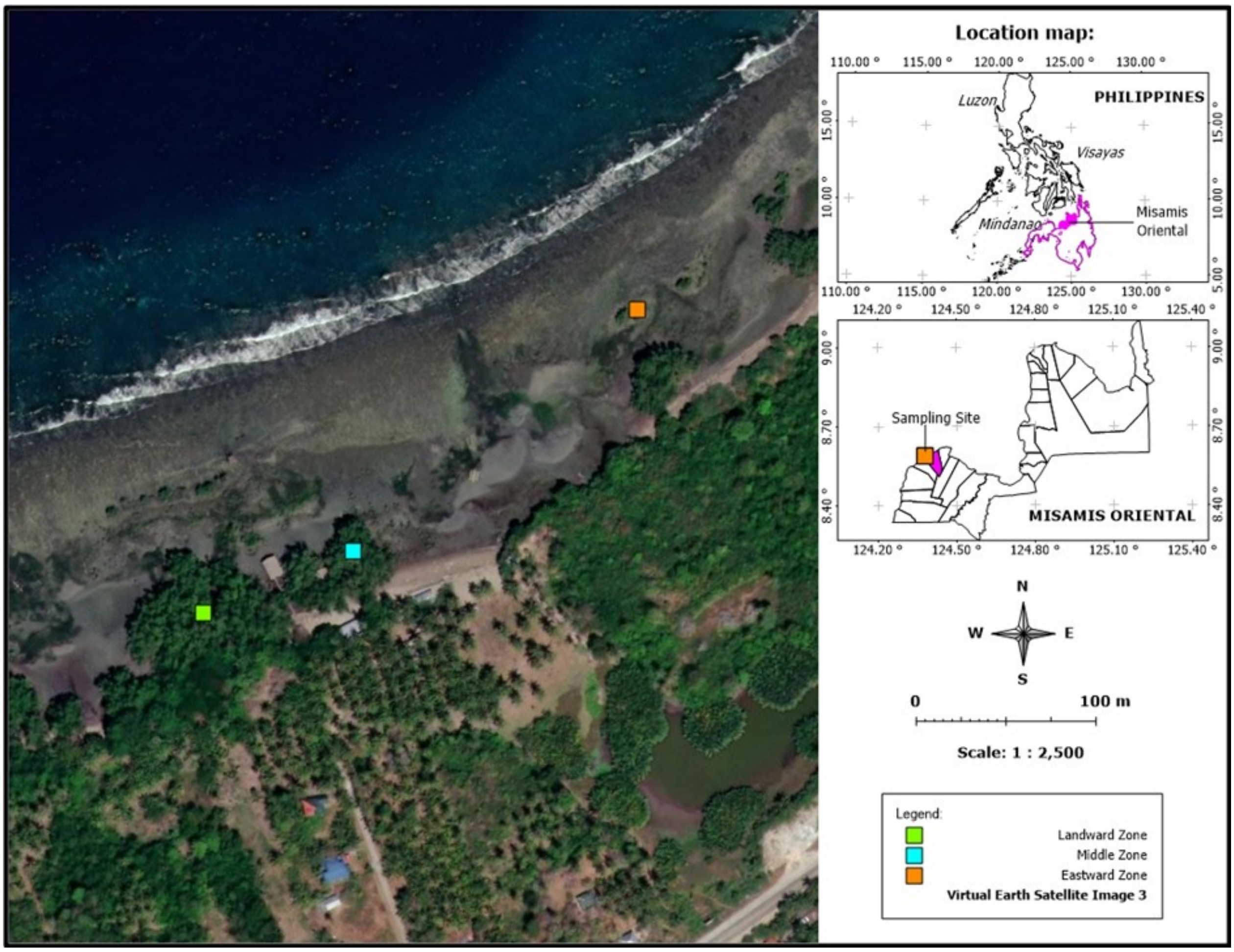

Figure 1. Location of the Mangrove Rehabilitation Site in the Municipality of Gitagum, Misamis Oriental, Mindanao Island, Philippines.

(100 m^2) sampling plot was established.

Station 1 (Figure 2) is in the landward zone of the mangrove area (8° 35'16.1"N 124°22'42.5"E). It is dominated by old-growth *S. alba* (Pagatpat) with a mixture of *R. mucronata* (Bakhaw babae). It has a hard substratum covered with pneumatophores and is abundant in marine fauna like gastropods and mudskippers.

Figure 2. Sampling Station 1 (Landward Zone).

Station 2 (Figure 3) was established in the middle zone of the mangrove area (8°35'17.2"N, 124°22'45.2"E); it consists of clumping new-growth *R. mucronata* (Bakhaw babae). The substratum is hard clay, and fauna associates (i.e., gastropods and mudskippers) were noticeably lower.

Figure 3. Sampling Station 2. (Middle Zone).

Station 3 (Figure 4) was established in the eastward zone of the mangrove area (8°35'21.5"N, 124°22'50.3"E); it consists of new-growth *A. marina* (Bungalon) and *R. apiculata* (Bakhaw lalaki). It has a sandy substrate that is covered with pneumatophores and rocks.

Figure 4. Sampling Station 3. (Eastward Zone)

Collection of Crabs in Mangroves

Crabs found on the ground, including those fleeing the plots, were manually collected by hand. Those found on trees were captured using a hand net, while those hiding in burrows were dug out with a trowel to a depth of 10-40 cm. Once collected, the specimens were placed in a plastic container filled with a small amount of seawater (Figure 5).

Figure 5. Collecting the crabs in different stations.

Physico-chemical Parameter Determination

The physico-chemical parameters such as air and water temperature, pH and substrate covers were determined. The air and water temperatures were measured using a thermometer. Water pH was measured using pH paper and a standard pH chart. The substrate cover in all sampling stations was determined by tactile and visual inspection.

Method of Taxonomic Identification

In preserving the collected specimens for identification, one to three representatives' samples were kept in a labelled container with ice and a small amount of seawater. It was then transferred to a glass jar container with 70 % ethanol. Using a ruler and digital calliper, the crabs were further measured from the center of the rear margin of the carapace or shell to the notch between the two front teeth that are most prominent, the crabs were then photographed, and compared to the publication, taxonomy key and pictorial guide of Motoh (1980), Huang et al. (1998), Ng (1998), and Subang et al. (2020). Guide on crab morphometrics (Figure 6) adapted from Vincecruz-Abeledo and Lagman (2018).

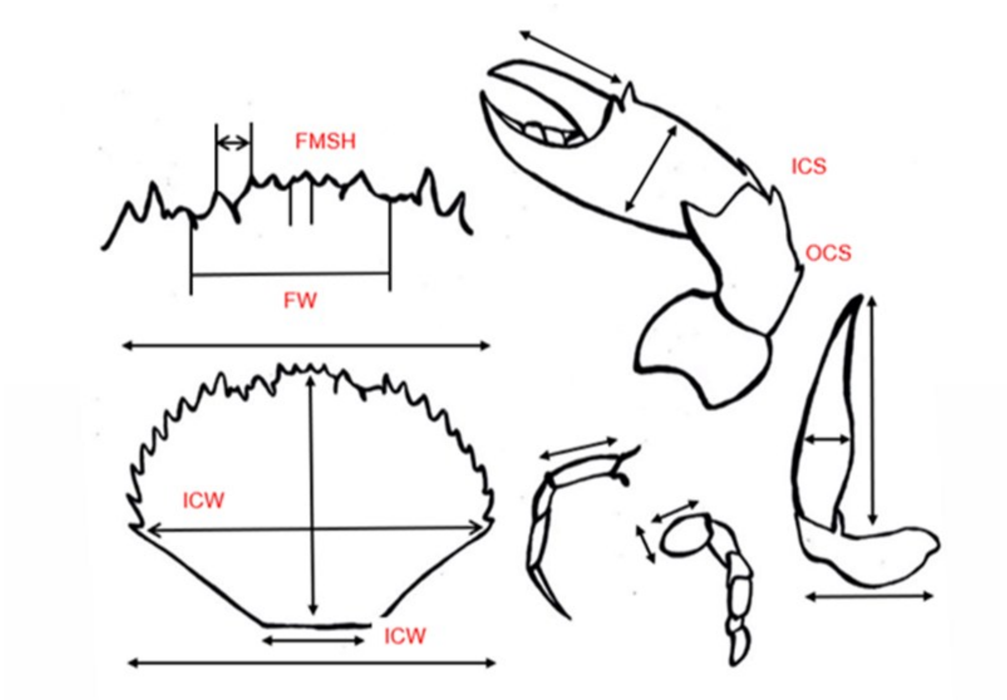

Figure 6. Guide on crab morphometrics. Frontal Median Spine Height (FMSH)), Frontal Width (FW), Inner Carpus Spine (ICS), Outer carpus spine (OCS), Inner Carapace Width (ICW).

Data Analysis

Relative Abundance

The species relative abundance was calculated using the formula of Mouillot and Lepretre (2000): Total Number of Individual species (Isi) divided by the Total Number of Species Population (∑ Nsi) multiplied by one hundred (100). Thus, Relative Abundance (%) = Isi/∑Nsi X 100

Where, Isi = Total Number of individual species; ∑ Nsi = Total Number of the species population.

Density

The density of crabs was estimated as the number of individuals that were captured per area (ind/m^2) De Lira et al. (2014):

D= N/A

where **D** is the density

N is the population size; and
A is the area.

Rarefaction and Extrapolation of Species Diversity

The Shannon-Wiener Diversity Index was calculated using the following equation (Shannon 1948).

$$\mathbf{H' = - \sum_{i=1}^{s} p_i \ln p_i}$$

Crab species diversity was analyzed using both asymptotic and non-asymptotic methods, based on widely used Hill numbers: q = 0 (species richness, Chao1), q = 1 (Chao Shannon diversity, H), and q = 2 (Chao Gini-Simpsons diversity, GS). Individual-based rarefaction and extrapolation (R/E) curves based on three diversity orders and a sample completeness curve were computed and plotted with 95 % confidence intervals. The aforementioned analysis was done using the iNEXT package of R version 3.6.3 (Hsieh et al. 2016; R Development Core Team 2020). This method was selected because of its ability to compare species richness despite differences in sampling effort and its ability to extrapolate at equal sample coverage (Chao et al. 2014).

RESULTS AND DISCUSSION

Species Composition, Richness and Relative Abundance of Crabs

A total of twelve (12) crab species were recorded in the mangrove rehabilitation project of Barangay Pangayawan, Gitagum, Misamis Oriental. These crab species belong to seven (7) families namely, Grapsidae (2 species), Varunidae (1 species), Mictyridae (1 species), Ocypodidae (2 species), Portunidae (4 species), and Xanthidae (2 species) (Table 1 and Figure 7).

Among the recorded crab species, the family Portunidae was the most represented group with four (4) species (*P. pelagicus*, *P. reticulatus*, *S. serrata* and *T. crenata*), followed by the families that tied with two (2) species: Ocypodidae (*G. tetragonon* and *P. crassipes*), and Xanthidae (*A. tomentosus* and *L. sanguineus*). Only one (1) species was recorded that belongs to the families Grapsidae (*Metopograpsus* sp.), Sesarmidae (*Clistocoeloma* sp.), Varunidae (*Ptychognathus* sp.) and Mictyridae (*M. longicarpus*). The members of the family Portunidae were the most dominant crab family found in Barangay Pangayawan, Gitagum, Misamis Oriental. In 2015, the Bureau of Fisheries and

Table 1. Species composition and relative abundance of crabs in three (3) selected sampling stations in Barangay Pangayawan, Gitagum, Misamis Oriental, Philippines.

Family	Species	Station 1	Station 2	Station 3
Grapsidae				
	Metopograpsus sp.	6	0	2
Mictyridae	*Mictyris longicarpus*	0	0	36
Ocypodidae	*Gelasimus tetragonon*	0	8	17
	Paraleptuca crassipes	0	3	8
Portunidae	*Portunus pelagicus*	12	0	2
	Portunus reticulatus	3	0	0
	Scylla serrata	8	0	2
	Thalamita crenata	6	1	4
Sesarmidae	*Clistocoelema* sp.	12	0	0
Varunidae	*Ptychognathus* sp.	0	3	0
Xanthidae	*Actaeodes tomentosus*	0	6	16
	Leptodius sanguineus	0	0	8
Total		47	21	95

Aquatic Resources (BFAR) released hundreds of juvenile crabs under this family (*S. serrata* and *P. pelagicus*) in the area (personal communication with Mr. Ted Manit of DENR, 2023). Mud crabs such as *Scylla spp.* have been likewise released in the mangroves of Naisud and Bugtong Bato, Ibajay, Aklan (Lebata 2006). The mud crab (*S. serrata*) and blue swimming crab (*P. pelagicus*) are among the most important crab species that contribute to Philippine economy (Lebata 2006; De La Cruz et al. 2018). Moreover, their dominance may also be explained by the fact that mangrove areas offer favorable environmental conditions that support the growth and reproduction of Portunidae crabs (Iromo et al. 2022). For instance, Portunidae crabs have a relatively short larval phase and may look for shallow and protected locations in the mangroves to release their offspring, which can attach to the pneumatophores and develop into juvenile crabs (Inam et al. 2023). These features of the mangrove habitat can contribute to the success of Portunidae crabs in these areas. Edible crabs such as *P. pelagicus, S. serrata, and T. crenata* were also commonly harvested crabs from marine and brackish ecosystems of Palawan (Subang et al. 2020) and La Union, Cabadbaran City (Anunciado et al. 2021). However, the inedible crab species are still understudied and rarely mentioned in existing literatures. Accordingly, the brachyuran fauna of the southern Philippine Islands of Mindanao is poorly known, with only few crab species described and recorded in the last 30 years (Lagare et al. 2020).

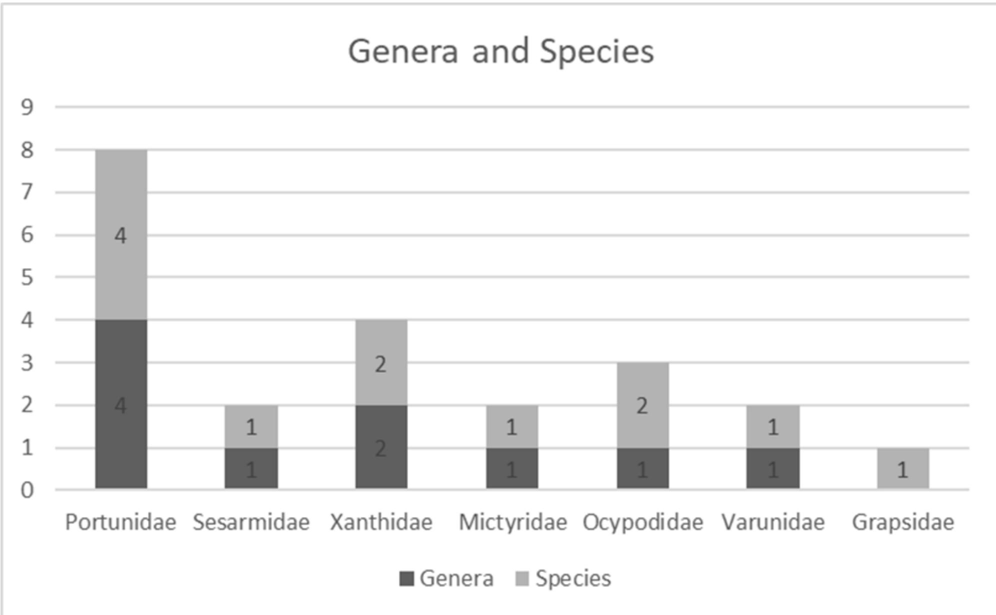

Figure 7. Species composition of crabs in Barangay Pangayawan, Gitagum, Misamis Oriental.

Family Grapsidae

Clistocoeloma sp. Saka-saka

Diagnosis: The carapace is generally subquadrate to hexagonal in shape and is typically wider than long. The dorsal surface is often ornamented with granules or tubercles, with a distinct median ridge or sulcus running anteroposteriorly along the centerline. The orbits house stalked, pedunculated eyes situated at the anterolateral corners of the carapace, which are typically small and pigmented black. The species possesses two chelipeds (pereiopods I), which are subequal in size and exhibit a characteristic curvature at the distal dactyli. The chelae are often adorned with setae or spinules, enhancing their tactile function. The walking legs (pereiopods II-V) are elongated and slender, with flattened meral segments and marginal supination or setation along the edges. Carapace dimensions range broadly among species within this group, from less than 1 cm (0.4 in) in smaller taxa to over 10 cm (4 in) in larger representatives (Figure 8).

Figure 8. *Clistocoeloma* sp. Saka-saka, (A) Dorsal view, (B) Ventral view.

Metopograpsus sp. Purple Climber Crabs
Diagnosis: *Metopograpsus* sp. (Figure 9) typically exhibits a carapace width ranging from 1 to 4 cm. The carapace is flattened dorsoventrally and has a transversely subquadrate shape. The dorsal surface is smooth and shiny, often with subtle granules or punctuations. The anterolateral margins are slightly curved, with distinct front regions and well-defined orbital margins. The chelipeds (pereiopods I) are relatively small compared to other crabs in similar habitats, often brightly coloured and smooth, with minimal ornamentation. The walking legs (pereiopods II-V) are elongated and slender. The eyes are small and situated on stalks (peduncles) that are highly mobile. *Metopograpsus* sp. possesses gills located within the branchial chambers near the base of the legs (Banerjee 1960; Fratini et al. 2018).

Figure 9. *Metopograpsus* sp. Purple Climber Crabs, (A) Dorsal View, (B) Ventral view.

Family Mictyridae

Mictyris longicarpus Latreille, 1806 Blue Soldier Crab
Diagnosis: *Mictyris longicarpus* (Figure 10) is characterized by an upright posture and a roughly spherical carapace. The body is predominantly white, with a powder-blue carapace and distinct purple markings at the leg joints. The carapace is smooth and dome-shaped, measuring up to 25 mm (0.98 inches) across, which is approximately the size of a cherry. The chelae (pereiopods I) are slender and held vertically in front of the crab's body, with dactyli curving downward in a characteristic manner. The eyestalk is short and positioned anteriorly (Holmquist 1989).

Family Ocypodidae

Paraleptuca crassipes (White, 1947) Thick-legged Fiddler Crab
Diagnosis: *Paraleptuca crassipes* (Figure 11) is a small to medium-sized fiddler crab, with carapace widths ranging from approximately 2 to 10 centimeters. The carapace is broader than long, with a smooth dorsal surface and distinct

anterolateral margin. The legs are robust, with the second and third pairs (pereiopods II and III) appearing thicker and more muscular. The chelae (pereiopods I) are markedly asymmetrical in males, with one claw significantly enlarged, while females exhibit small, symmetrical chelae. The eyestalks are long and mobile (Neely 2023).

Figure 10. *Mictyris longicarpus* Latreille, 1806 Blue Soldier Crab, (A) Dorsal view, (B) Ventral view.

Figure 11. *Paraleptuca crassipes* (White, 1947) Thick-legged Fiddler Crab, (A) Dorsal view, (B) Ventral view.

Gelasimus tetragonon (Herbst, 1790) Fidler Crab
Diagnosis: *Gelasimus tetragonon* (Figure 12) is a small to medium-sized fiddler crab, with carapace widths ranging from approximately 1 to 5 centimeters, occasionally reaching up to 6 centimeters. The carapace is transversely subquadrate and flattened, with smooth to slightly granular surfaces. The anterolateral margins are rounded, and the frontal region is narrow, with well-developed orbital grooves. The species exhibits strong sexual dimorphism in the chelae (pereiopods I). Males have one greatly enlarged claw, while the other claw is small. Females, by contrast, possess two small, symmetrical chelae. The walking legs (pereiopods II-V) are long and slender. The eyestalks are highly mobile. Coloration is variable, ranging from shades of brown, gray, and white to more vibrant hues, often with stripes or intricate patterns (Cumberlidge & Daniels 2009).

Portunus pelagicus (Linnaeus, 1758) Blue Swimmer Crab
Diagnosis: The carapace of *Portunus pelagicus* (Figure 13) is broadly hexagonal in shape, with a smooth dorsal surface and a pair of small, prominent anterolateral teeth near the front. The carapace is widest at the level of the fourth anterolateral tooth and tapers posteriorly. Its overall coloration is typically bluish-green, with variations in shading, including lighter or darker markings. The chelipeds (pereiopods I) exhibit pronounced sexual dimorphism. The larger claw is notably more developed, with the right claw being larger in males and the left claw larger in females. The larger claw is flattened, with a smooth inner surface and a broader, more robust structure, while the smaller claw is more pointed, toothed, and narrower. The walking

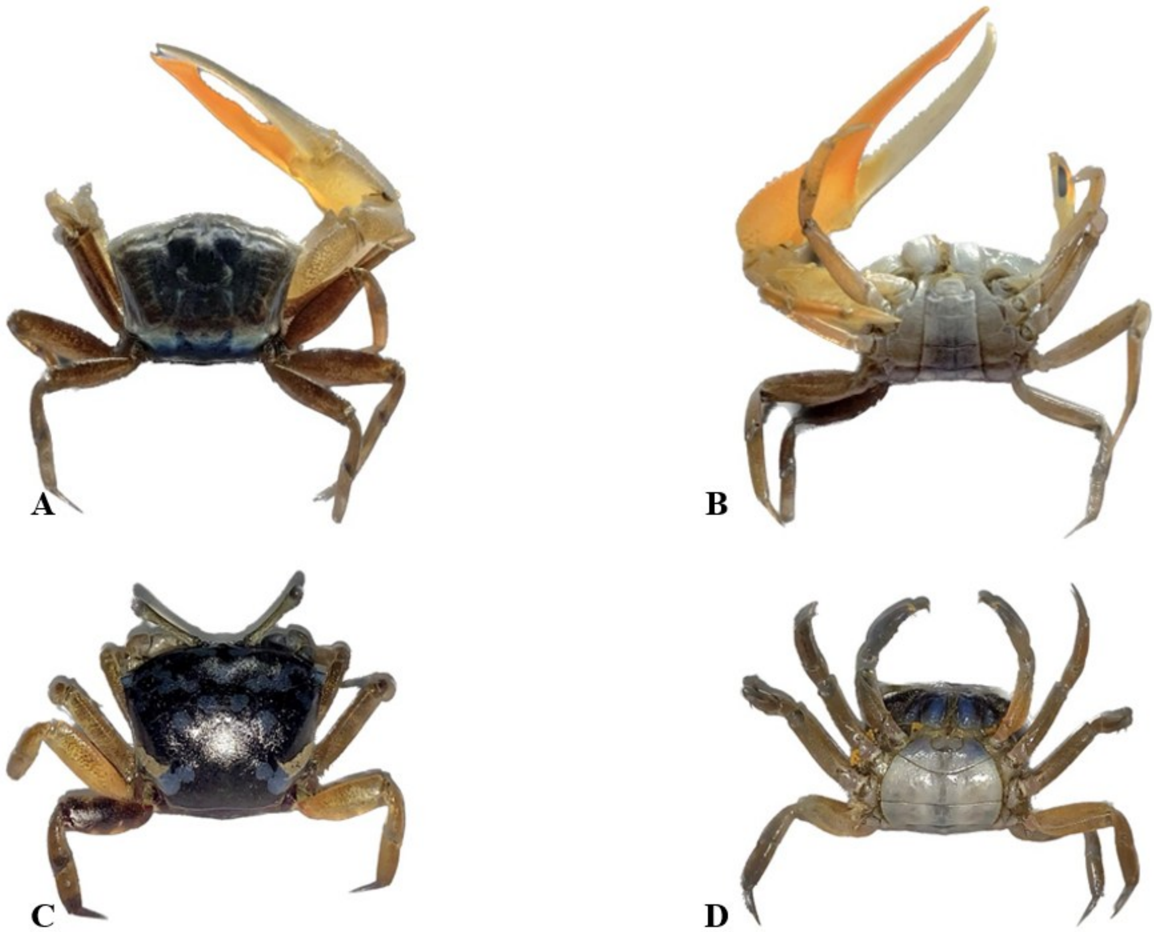

Figure 12. *Gelasimus tetragonon* (Herbst, 1790) Fidler Crab, male (A, B); female (C, D).

legs (pereiopods II-V) are long, slender, and adapted for swimming, with flattened meral segments and small spines or setae along the edges. Adults of *Portunus pelagicus* typically range in carapace width from 10 to 20 cm (4 to 8 in), with males generally being slightly larger than females (Toring-Farquerabao & Tahiluddin 2022).

Portunus reticulatus (Linnaeus 1758) Swimmer Crab
Diagnosis: *Portunus reticulatus* (Figure 14) possesses an oval-shaped carapace characterized by nine prominent anterolateral teeth on each side, along with four triangular frontal teeth located between the eyes. The carapace surface is smooth, although fine granulation may be present in some specimens. The chelipeds (pereiopods I) are significantly larger and more elongated than the walking legs. The claws are smooth and robust, with a long slender shape (Spiridonov et al. 2021).

Scylla serrata (Forsskål, 1775) Mangrove Crab or Mud Crab
Diagnosis: *Scylla serrata* (Figure 15) features a robust, oval-shaped carapace with nine prominent anterolateral teeth on each side and four triangular frontal teeth between the eyes. The carapace is typically smooth, although it may exhibit slight granulation in some individuals. The carapace width can exceed 250 mm in larger specimens, with some reaching sizes up to 30 cm or more. The chelipeds (pereiopods I) are significantly larger and more powerful than the walking legs. The chelae are highly asymmetrical, with the larger claw being more refined (Khaksari et al. 2022).
Thalamita crenata Rüppell, 1830 Spiny Rock Crab
Diagnosis: *Thalamita crenata* (Figure 16) has a rounded carapace with five distinct anteromedial teeth along the front margin. The carapace surface is typi-

Figure 13. *Portunus pelagicus* (Linnaeus, 1758) Blue Swimmer Crab, male (A, B); female (C, D).

Figure 14. *Portunus reticulatus* (Linnaeus, 1758) Swimmer Crab, (A) Dorsal view, (B) Ventral view.

cally smooth, with three pairs of well-defined gastric ridges, located on the dorsal side. In males, the first pleopod is notably long and slender (Diggles et al. 2020).

Family Varunidae

Ptychognathus sp.

Diagnosis: The carapace of *Ptychognathus* (Figure 17) is longer than wide, with flat, depressed dorsal surfaces. Regions are not well indicated. It lacks a distinct postero-lateral facet, and the antero-lateral margins are toothed behind the exorbital angles. Third maxillipeds feature a broad exopodite, typically wider than ischium, with a merus articulated at distal outer angle and a non-oblique merus-ischium suture. Chelipeds are unequal, outer surfaces of chela often with a tuft of hairs near the base of fingers. Ambulatory legs lack spinules on the posterior border of merus; dactyli not flattened (Hsu & Shih 2020).

Figure 15. *Scylla serrata* (Forsskål, 1775) Mangrove Crab or Mud Crab, (A) Dorsal view, (B) Ventral view.

Figure 16. *Thalamita crenata* Rüppell, 1830 Spiny Rock Crab, (A) Dorsal view, (B) Ventral view.

Figure 17. *Ptychognathus* sp., (A) Dorsal view, (B) Ventral view.

Family Xanthidae

Actaeodes tomentosus (Milne-Edwards, 1834)

Diagnosis: *Actaeodes tomentosus* (Figure 18) has generally square-shaped carapace with four prominent anterolateral teeth on either side. The carapace surface is often smooth or slightly granular. The legs are relatively short and stout. They are usually sparsely covered in fine hairs or small spines. The chelae are large, asymmetrical, and powerful, with the larger claw used for defense, communication, and foraging. The smaller claw is more refined for handling food and performing delicate tasks. Coloration varies among individuals, typically ranging from shades of brown, orange, and yellow. However, *Actaeodes tomentosus* generally exhibits more muted tones compared to more vividly colored Xanthid species. The size is typically much smaller, with carapace widths ranging from about 1 cm to a maximum of 5 cm (Balachandran et al. 2021).

Figure 18. *Actaeodes tomentosus* (Milne-Edwards, 1834), (A) Dorsal view, (B) Ventral view.

Leptodius sanguineus (Milne-Edwards, 1834)
Diagnosis: *Leptodius sanguineus* (Figure 19) has a carapace that is generally hexagonal or transversely ovate, occasionally appearing circular in some individuals. The dorsal surface of the carapace is typically ridged or granulose. The frontal margin is notched medially, and the anterolateral margins usually bear 2 to 6 spines, teeth, or lobes, contributing to the overall shape of the carapace. The legs exhibit notable structural variation, with the propodus and dactylus showing a unique dactylo-propodal articulation. In males, the abdominal segments III to V are fused or partially united. The second gonopod in males is very short, measuring less than one-fourth the length of the first gonopod, which is slender and slightly sinuous (Serène 1984).

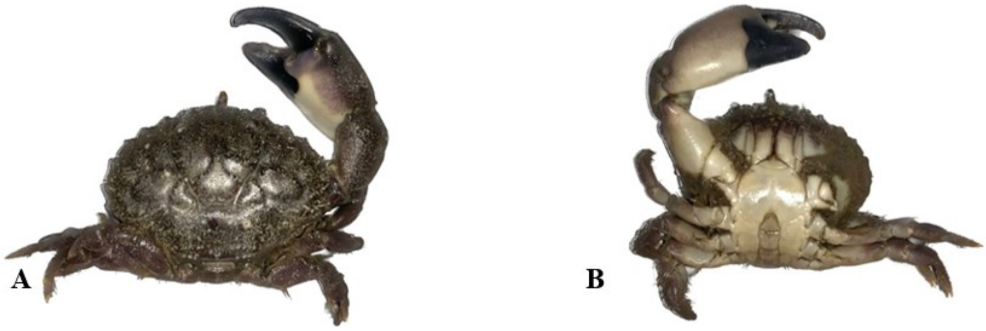

Figure 19. *Leptodius sanguineus* (Milne-Edwards, 1834), (A) Dorsal view, (B) Ventral view.

In terms of species richness, a total of twelve (12) brachyuran crabs representing seven (7) families (Sesarmidae, Mictyridae, Ocypodidae, Portunidae, Grapsidae, Varunidae, and Xanthidae) were found in the mangrove rehabilitation site of Barangay Pangayawan, Gitagum, Misamis Oriental. This represents 46.154% of the twenty-six (26) crabs identified and recorded in Mindanao (Lagare et al. 2020). The highest species richness was recorded in station 3 with nine (9) crab species collected, followed by station 1 with six (6) species and station 2 with only five (5) species (Figure 20).

The distribution of crab species varied and overlapped in the three stations (Figure 20 and Table 2). Though *Thalamita crenata* was present in all three stations, some species had limited spatial distribution. *P. reticulatus* and *Clistocoelema* sp., for example, were only found in Station 1 while *Ptychognathus* sp. had been recorded only in Station 2. On the other hand, both *M. longicarpus* and *L. sanguineus* have only been documented at Station 3. However, station 3 showed to harbor a number of species that also exist in other stations. These include *Metopograpsus* sp., *S. serrata*, and *P. pelagicus* which also thrives in Station 1, and *P. crassipes*, *H. orientalis* and *G. tetragonon* which were previously recorded in Station 2. As such, the highest number of recorded crab species was found in station 3. This finding follows the previously described interrelationship between the mangrove forest and brachyuran crabs. Accordingly, mangrove forests with high species richness and diversity tend to harbor high number of brachyuran crabs and other macrofauna (Ravichandran et al. 2011; Lapolo et al. 2018). In the Gitagum Mangrove Rehabilitation Project, Station 3 had the highest diversity of mangroves (H' = 1.45) which indicates that it has the most diverse mangrove composition compared to Station 2 (H' = 1.19) and Station 1 (H' = 0) (Taneo & Areola 2022).

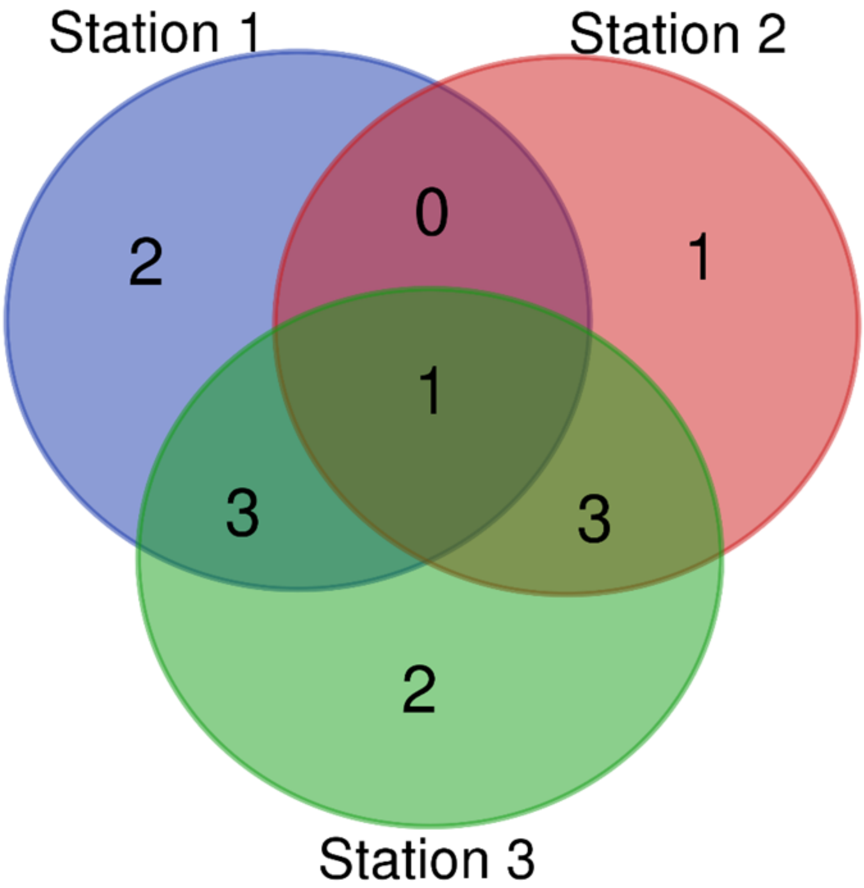

Figure 20. Venn diagram showing the distribution of crab species in the three stations.

Table 2. Spatial distribution of crab species in the three stations

Location	Total number of species	Elements
Station 1, Station 2, and Station 3	1	*T. crenata*
Station 1 and Station 3	3	*Metopograpsus* sp., *S. serrata* and *P. pelagicus*
Station 2 and Station 3	3	*P. crassipes*, *A. tomentosus* and *G. tetragonon*
Station 1	2	*P. reticulatus* and *Clistocoelema* sp.
Station 2	1	*Ptychognathus* sp.
Station 3	2	*M. longicarpus* and *L. sanguineus*

Moreover, the presence of rocks and pneumatophores in Station 3 can create a diverse microhabitat, allowing different crabs species to utilize different areas of the substrate. Additionally, these habitats can also support a greater abundance and diversity of prey items, which can attract more crab species that feed on them (Naderloo et al. 2013). This explains why the species richness of poisonous crabs from the family Xanthidae (*A. tomentosus* and *L. sanguineus*) may be high in Station 3. According to the locals, these crab species are also often overlooked or avoided when crabbing as they are not suitable for consumption due to their toxic nature. Their populations may not be as heavily exploited as those of other crab species, such as the *S. serrata* and *P. pelagicus*. As a result, their populations may be less affected by overfishing or other human activities, allowing them to thrive and potentially reach higher densities in the mangrove site. Crab populations can naturally fluctuate in response to various ecological factors, such as changes in food availability or predation pressure (Nakaoka 2000). On the other hand, *S. serrata* and *P. pelagicus* have been commonly harvested in many parts of the Philippines, including Puerto Princesa, Palawan, as they are commercially important due to their high economic value and significant contribution to the country's fishing industry (Subang et al. 2020).

Relative Abundance

A total of one hundred sixty-three (163) individuals of brachyuran crabs were collected in the three (3) sampling stations in the mangrove rehabilitation site of Barangay Pangayawan, Gitagum, Misamis Oriental (Table 1). Station 3 had the highest abundance with ninety-five (95) individuals, followed by station 1 with forty-seven (47) individuals and lastly, station 2 with twenty-one (21) individuals. Different species of crab could have distinct preferences for certain mangrove vegetation structure and complexity (Li et al. 2018). The substrate and the open-canopy mangrove forest in Station 3 could also influence the high abundance of crab species. Accordingly, sandy substrates covered by rocks and pneumatophores are suitable for the reproduction of crabs (Flores & De Paula 2001). Rocky areas protect the crabs from predators and environmental conditions such as waves and currents (Ens et al. 2022).

Out of the 163 crabs collectedacross the three stations, 36 of which were *M. longicarpus*, which are known to live in groups, particularly during their mating season (Hughes et al. 2014). Station 3, which has a soft sandy substrate, was found to be an ideal habitat for *M. longicarpus* because they require soft mud or sand for their burrowing activities (Dittmann 1998), and mangrove areas with rich organic sediments provide the necessary conditions for their burrowing (Rossi & Chapman 2003). Among the three sampling sites, *Metopograpsus* sp. (Saka-saka) was only found in Station 1, which has a hard substratum and is dominated by old-growth *S. alba* (Pagatpat). These old-growth mangrove trees provide a more stable environment for the *Metopograpsus* sp. (Saka-saka) to climb, providing more opportunities for them to find suitable habitats such as tree trunks and branches. *Metopograpsus* sp. seem to effectively utilise their ability to climb trees, which has been observed in mangroves forests of Asia, including the Philippines (Sivasothi 2000). Six distinct types of tree-climbing crabs were recognized in Anibong Bay, Tacloban City (Matillano et al. 2018), and have also been documented in mangrove areas in Capiz (Leonida 2020). *Clistocoeloma* sp. remains on trees throughout the day and do not come down to the mangrove forest floor as they hide in crevices and holes on tree trunks or between the bark during low tide.

Density

In terms of density, *M. longicarpus* had the highest species density of 0.12 individuals/m^2. This was followed by *G. tetragonon* (0.08 individuals/m^2), *A. tomentosus* (0.07 individuals/m^2), *P. pelagicus* (0.04 individuals/m^2), *Clistocoeloma* sp. (0.04 individuals/m^2), *T. crenata*, *P. crassipes* (0.03 individuals/m^2), and *S. serrata* (0.0333 individuals/m^2), *Metopograpsus* sp. and *L. sanguineus* (0.02 individuals/m^2) *Ptychognathus* sp. and *P. reticulatus* (0.01 individuals/m^2), respectively (Figure 21). The different mangrove types and zonation in the area may be particularly well-suited to the needs of the crab species (Wong & Barbeau 2003). Mangrove forests are not uniform, and they vary in composition and structure based on various factors such as tidal inundation, salinity, and sediment type. These variations can create distinct zonation patterns within the mangrove ecosystem (Lai et al. 2022). Also, the different mangrove types and zonation in the area may provide diverse microhabitats for different species of crabs, with each species having unique requirements for food, shelter, and breeding.

Some species, like *Parasesarma leptosoma*, spend their entire lives on the roots and branches of mangrove trees and it never enter the water, nor do they venture onto the free mud surface at low tide (Vannini & Ruwa 1994). Moreover, certain crab groups are known to thrive in specific mangrove types. An example is Ocypodoidea which is known to be predominated over Grapsoidea in the smaller mangrove areas in pioneer stages of mangrove forest establishment, whereas the opposite was recorded for larger and more stable mangrove forests, where the forest can reach the advanced stage of development (Colpo et al. 2011). Similarly, different species of crabs may require different types of substrates such as soft mud or sand, rocks, or pneumatophores for burrowing or shelter (Flores & De Paula 2001; Seitz 2012). As such, the suitability of the different mangrove types and substrate types to the specific needs of crab species can affect their abundance and distribution within the mangrove ecosystem. Rather than the water quality parameters, the sediment quality parameters appeared to influence the distribution of crabs (Devi et al. 2021). In addition, the distribution of crabs was observed to be the highest in the stations with muddy substratum, with high organic carbon content and comparatively high amount of moisture as well as ornamented with luxuriant mangrove patches (Devi et al. 2021). Such condition provides substantial food source preferred by certain crab species. The fiddler crabs, in particular, preferred to forage on yellow mangrove leaves suggesting their vital role in nutrient cycling in the mangrove area (Nallos & Macusi 2023). *M. longicarpus* has the highest density, as it mates and lays it eggs in the sandy substrate, which provides protection and stability for the eggs. The sandy substrates may provide an ideal environment for the development and survival of ghost crab eggs and larvae (Cameron 1966).

Edible crabs such as *S. serrata* and *P. pelagicus* are highly valued as they are an important source of food and income for the locals in Barangay Pangayawan. According to the locals, crabbing and fishing in Gitagum were indispensable means of livelihood, particularly for those who have limited access to other employment opportunities in the municipality. On the other hand, inedible crabs such as *A. tomentosus* and *L. sanguineus* have been avoided by the locals in the area. The avoidance of these crabs by the locals of Gitagum is a prudent strategy given the potential harm that can be caused by ingesting them. Inedible crabs like those in the Xanthidae family contain toxic substances that can pose a risk to human health (Fredrick et al. 2011), and as a result, they cannot be sold in the local market. This traditional knowledge of avoiding these crabs demonstrates the importance of local ecological knowledge in maintaining the health and well-being of communities that rely on seafood, such as those in Gitagum.

Diversity

In terms of species diversity, station 3 (Eastward zone) exhibited the highest diversity among the three stations, with H' = 1.770. This is followed by station 1 (Landward zone), which has a diversity index value of H' = 1.700, indicating a slightly lower level of diversity than station 3 (Table 3). Lastly, station 2 (Middle zone) has the lowest diversity index value of H' = 1.427, suggesting a lower diversity of crab species compared to the other two stations. This may be explained by the higher species composition, abundance, and density in Station 3 compared to the two stations. Station 3 which is dominated by the new-growth mangroves within the rehabilitation site, was shown to harbor more species and population of crabs compared to the old-growth mangrove area. This finding suggests the importance of mangrove rehabilitation sites for supporting diverse crab communities. The high species composition and density of new-growth mangrove species in Gitagum (Taneo & Areola 2022) provide the necessary microhabitat and food source (e.g., decaying mangrove leaves) preferred by brachyuran crabs.

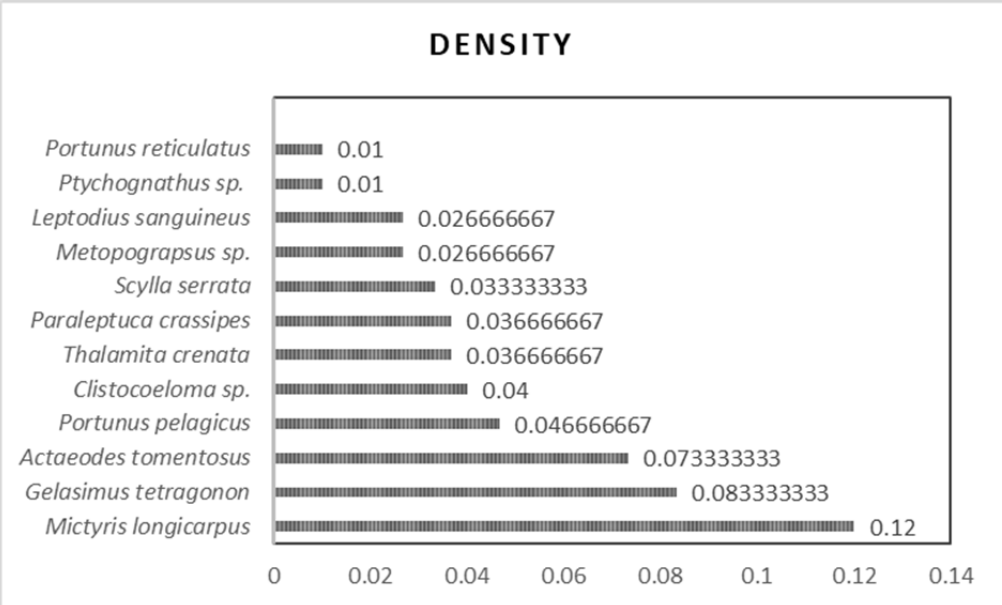

Figure 21 . Density of crab species in Gitagum Mangrove Rehabilitation Project.

As the mangrove ecosystem in the area improves, the availability of food sources for different crab species, such as fallen leaves and detritus, may increase, providing more shelter and hiding places for crabs. This can reduce predation pressure (Vermeiren et al. 2015) and allow for a greater crab species diversity in the mangrove rehabilitation site. Recent studies conducted in other mangrove sites in the Philippines found that Basilan has recorded twenty-three crabs species (Jingkatal & Ramos 2019). Similarly, a recent survey in Mindanao recorded twenty-six crab species across 22 sampling localities (Lagare et al. 2020).

Table 3. Shannon-Weiner Diversity

Stations	Diversity Index Value
Station 1	H' = 1.700
Station 2	H' = 1.427
Station 3	H' = 1.770

Rarefaction Curve Analysis

The rarefaction and extrapolation curves (Figure 22) showed that stations 1 and 2 curves tend to plateau, suggesting adequate sampling effort in the aforementioned sites. However, in Station 3, the sampling curve is still increasing, indicating the need for additional field sampling.

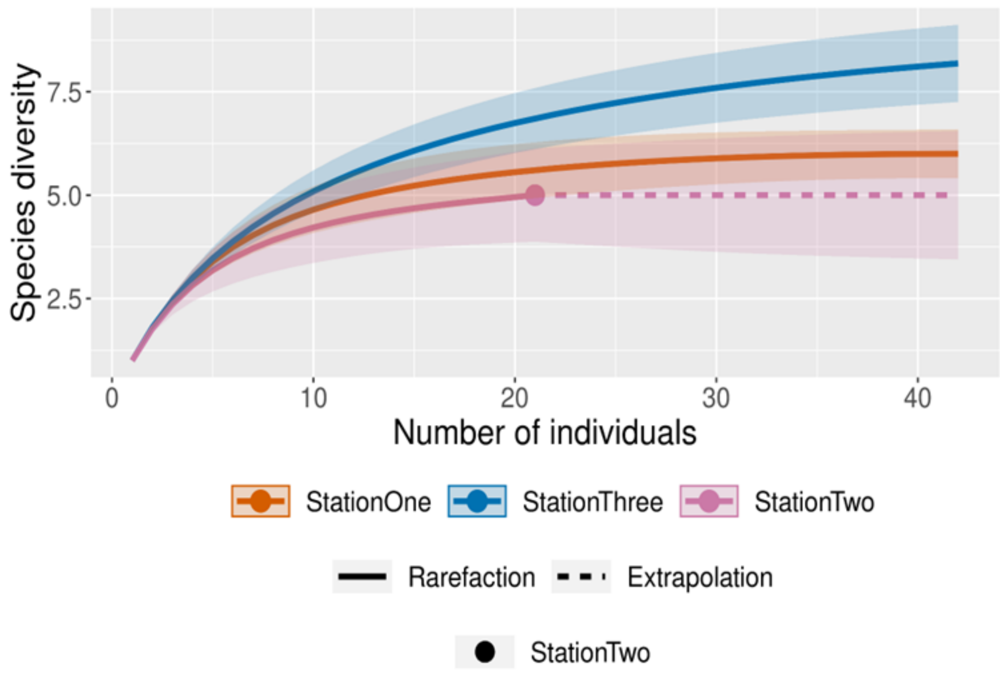

Figure 22. Sample-sized-based rarefaction and extrapolation sampling curve.

Physico-Chemical Parameters

The air and water temperatures, pH, and substrate type were measured and recorded in the three stations (Table 4). The air temperature ranged from 28.8 to 30.2 °C, while the water temperature ranged from 26.5 to 28.0 °C. The average water pH during the sampling period was 9, which shows alkalinity.

Table 4. Physico-chemical parameters in the three sites of the mangrove rehabilitation project

Station	Air	Water	pH	Substrate
1	29.6 °C	26.5 °C	9	Hard Clay
2	28.8 °C	27.2 °C	9	Hard Clay
3	30.2 °C	28.0 °C	9	Sandy

Accordingly, physico-chemical parameters such as air and water temperatures, pH levels, and substrate types can influence the richness, abundance, density and diversity of crabs in mangrove areas (Al-Khayat & Giraldes 2020). Temperature can have a direct effect on the physiology of crabs. Portunidae crabs are sensitive to changes in water temperature, which can affect their metabolism, growth, and reproduction (Syafaat et al. 2021). Higher water temperatures may increase the activity and feeding rates of Portunidae crabs, while lower water temperatures may decrease their activity levels. However, extreme temperatures can also be stressful or lethal for these crabs (Kuhn & Darnell 2019). Different species of crabs may have different pH preferences, and some may be more tolerant of temperature fluctuations than others (Mokhtari et al. 2015). For example, some crabs may be adapted to living in more acidic or alkaline waters.

Changes in pH can also affect the availability of nutrients and other resources, which may indirectly affect the abundance and diversity of crabs (Spivak et al. 1994). Regarding substrate type, some crab species may be adapted to rocky or coral substrates, such as those from the family Xanthidae, while others may prefer muddy or sandy substrates like the *M. longicarpus* and *G. tetragonon* (Knudsen 1960), which explains the abundance in Station 3. Changes in sediment type, such as the accumulation of sand or other sediments, can affect their ability to construct and maintain burrows, which can affect their survival and reproduction (Feller & Nybakken 1983).

CONCLUSIONS

In conclusion, a total of one hundred and sixty-three (163) individuals in twelve (12) species of brachyuran crabs belonging to seven (7) families were recorded at the site. Station 3 (Eastward zone) had the highest abundance with ninety-three (93) individuals, followed by Station 1 (Landward zone) with forty-seven (47) individuals, and Station 2 (Middle zone) with twenty-one individuals collected. The species *Mictyris longicarpus* had the highest population density of 0.12 individuals/m^2, while *Ptychognathus* sp. and *Portunus reticulatus* had the lowest, with a population density of 0.01 individuals/m^2. Brachyuran crabs are more abundant and diverse in new-growth mangroves compared to the old-growth mangroves. The Shannon-Weiner diversity index revealed that Station 3 (Eastward zone) had the highest diversity (H' = 1.770), compared to Station 1 (H' = 1.700) and Station 2 (H' = 1.427). The result of the study confirms the hypothesis that new-growth mangroves harbor a relatively diverse species of crabs compared to old-growth mangrove forest.

Consequently, a comprehensive taxonomic investigation of the crab species is recommended, as relevant field guides are unavailable, and there is still a need for local expert on crab taxonomy. Moreover, it is highly recommended that the Gitagum mangrove rehabilitation site be officially declared a marine protected area and that regulations be enforced in partnership with the local communities.

AUTHOR CONTRIBUTION

CFVAB drafted the first version of the manuscript. CFVAB and DPB contributed in the fieldwork, data collection, and analysis. This research project was supervised by DPB.

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CONFLICT OF INTEREST

There are no conflicts of interest regarding this research or its funding.

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