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RESEARCH ARTICLE

Assessment of Mud Crab Fishery in Panguil Bay

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ABSTRACT

The last assessment of three commercially important mud crab species (*Scylla tranquebarica, S. olivacea* and *S. serrata*) in the mangrove dominated Panguil Bay was in 2005; there was already an indication of the stock decline. This study aimed to continue the assessment but focused on production, growth parameters, total mortality, and exploitation rate of the three mud crab species at seven mud crab landing sites from March 2017 to March 2019 following standard fisheries enumeration protocols. Results showed that the total resource production in Panguil Bay decreased from 201.1 MT in 2005 to 103.0 MT in 2017-2019. Growth parameters of the three species for male and female, respectively are as follows: *S. tranquebarica* ($L\infty$ = 11.5 cm and 11.7 cm, annual growth coefficient K = 0.6 and 0.6, exploitation rate E of 0.5 and 0.5); *S. olivacea* ($L\infty$ =10.9 cm and 11.4 cm, K = 0.5 and 0.6, E = 0.6 and 0.5); and *S. serrata* ($L\infty$ = 12.3 cm and 12.9 cm, K = 0.7 and 0.6, E = 0.6 and 0.6). Total production of mud crabs increased, and the three species are highly exploited, but exploitation rates are already slightly below or above maximum sustainable yield (E_{max}). A total of 1,848 fishers were recorded owning 2,015 boats composed of 1,419 motorized and 596 non-motorized. An inventory showed an increase of 5.36% in the number of motorized boats from the last assessment in 2005. A total of 15 types of gear were recorded, in which the top three include fish corral, crab pot, and gill net. Consequently, this study recommends reducing the present fishing pressure or effort of the three mud crab species, particularly during the spawning season occurring on wet months (July to October), for sustained mud crab fisheries in Panguil Bay.

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1. INTRODUCTION

Panguil Bay is a small but rich fishing ground that supports thousands of small-scale fishers in northwestern Mindanao. Historically it is a rich fishing ground of wild shrimps and crabs. In the past study conducted by Jimenez et al. (2009), it was observed that the landed catch of crustaceans was dominated by three mud crab species, namely: the giant mud crab (*Scylla serrata*), purple mud crab (*S. tranquebarica*), and orange mud crab (*S. olivacea*). Since 2005, very few follow-up studies have been carried out on the fisheries biology of these commercially important crab species (Jimenez et al. 2009). The three species and the fourth *S. paramamosain* are now resolved as four distinct *Scylla* species (Fazhan et al. 2020).

Mud crabs are known to be at the top of the list of export-earning aquatic resources in Panguil Bay due to their high demand and reasonable price (Rivera et al. 2017). The export of mud crab from Panguil Bay has widely increased over time due to its huge availability and high demand in the live mud crab market (Rivera et al. 2017). This market scenario may result in high mud crab fishing activities and eventually a sudden decrease of the stock. However, existing knowledge about the status of the stock of the three mud crab species in Panguil Bay is unclear since its previous stock assessment study (Jimenez et al. 2009).

Regulatory instruments such as spatial and temporal restrictions, gear ban, and mesh regulations need to be undertaken. They must still be based on scientific data to attain sustainable fisheries and rational resource management (Dickson 2009). Policy measures need to be supported with data from assessments that yield biological information (Jimenez et al. 2009). Stock assessment is one way to check a particular fishery's status before a policy recommendation is lobbied. Before a policy could take effect, comprehensive scientific data will have to be produced as the basis. Hence, this study aims to conduct a stock assessment of the mud crab fishery in Panguil Bay. Specifically, it seeks to:

1. Assess the population parameters and recruitment patterns of the three mud crab species (*S. tranquebarica, S. olivacea, S. serrata*) in Panguil Bay;
2. Make an inventory of fisherfolk fishing boat and gears involved with mud crab fishery;
3. Know the catch species composition associated with the mud crab fishery;
4. Determine the Catch Per Unit Effort (CPUE); and
5. Determine the sex ratio, gonad maturity, and GSI of the three mud crab species.

2. MATERIALS AND METHODS

2.1 Landing centers/sampling areas

The sampling stations were established based on the known coastal landing areas in Panguil Bay identified in 2005 (Jimenez et al. 2009), namely: Municipalities of Kapatagan, Lala, Baroy and Kolambugan in Lanao del Norte; Tangub City and the Municipality of Bonifacio, Misamis Occidental; and the Municipality of Aurora, Zamboanga del Sur (Figure 1). The sampling at these sites would allow comparison of results between this and past studies.

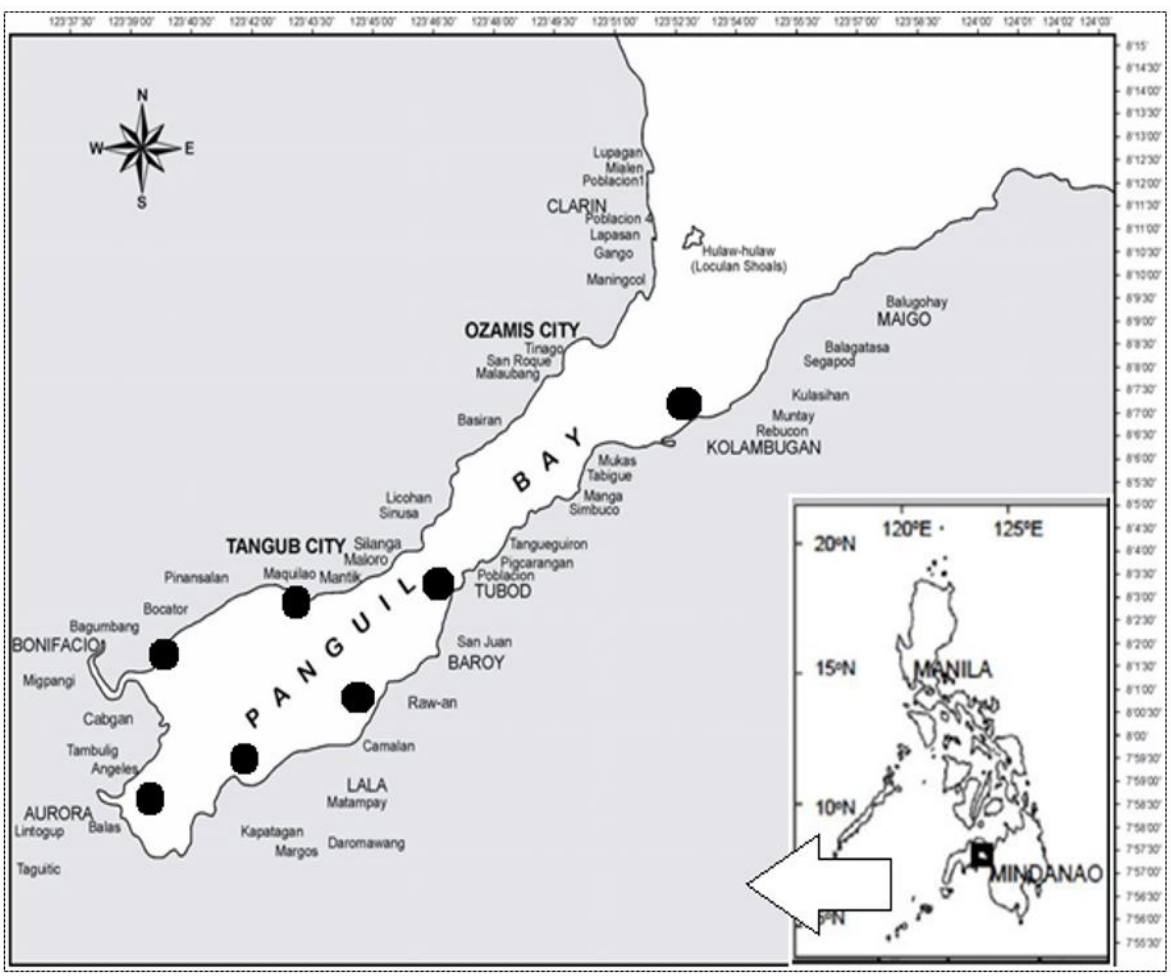


Figure 1. Map showing the location of mud crab landing sites at Panguil Bay where sampling for this study was undertaken. Insert is the map of the Republic of the Philippines showing the location of Panguil Bay (square).

2.2 Data collection

Data on the number of fisherfolk, fishing boat, and gear were collected and recorded by the enumerators from the fisherfolk registry of the Office of the Municipal Agriculturist (MAO). On-site fisheries enumeration was done to validate the records.

Landed catch survey of the three mud crab species, namely, *S. serrata, S. olivacea* and *S. tranquebarica* was conducted from March 2017 to May 2019 by trained fisherfolk enumerators using a standard survey form on catch and effort. The survey was done for two days intervals or 20 days in a month, including Saturdays, Sundays, and holidays. Sex of mud crabs was determined, and the survey forms (see Appendix A) include the following data gathered: biological parameters carapace length (CL) to the nearest 0.1 cm using the vernier caliper and body weight (BW) to the nearest 0.1 g using digital weighing, landing site, fishing ground, the volume of catch per species, type and number of gear and boat used, and the number of fishing operation hours. All survey forms were collated and processed monthly.

2.3 Data analysis

2.3.1 Population parameters

The mud crab length-frequency data from the major fishing gears, namely fish corral, crab pot, and gill net, were analyzed. Carapace length of mud crab samples per month was measured to construct the length-frequency data. The data were processed using the FAO-ICLARM Stock Assessment Tool or FiSAT II version 1.2.2 software (Gayanilo et al. 1997). Annual recruitment patterns were derived for males and females of the three mud crab species also using FiSAT II. Growth parameters were determined first by estimating the initial asymptotic length ($L\infty$) and the ratio of the total mortality to growth coefficient (Z/K) using the Power-Wetherall method (Gayanilo and Pauly 1997) based on the equation of Beverton and Holt method (1956). The initial seed value of $L\infty$ was further analyzed in ELEFAN I (Electronic Length Frequency Analysis), where the constant (K) was estimated from the k-scan routine finding the best appropriate growth curve. Estimated $L\infty$ and K values were visually assessed for progression of modes in the growth curve utilizing the von Bertalanffy Growth Function or VBGF (Pauly 1983). The mortality parameters (Z, M, and F) and Exploitation Rate (E) were estimated via the Length-Converted Catch Curve method (Pauly 1984) and using the mean annual habitat temperature of 30°C. Z is the total instantaneous mortality, M is natural mortality, and F is mortality caused by fishing. The instantaneous Total Mortality (Z) was estimated following the formula:

$$Z = M + F$$

Expanding the equation for mortality would lead to the estimation of Exploitation Rate (E) via the following equation:

$$E = \frac{F}{Z}$$

Level of exploitation of stocks used the following categories: (a) E below -10% of $E_{0.1}$ suggests underexploited; (b) E = -10% of $E_{0.1}$ to E = +10% of $E_{0.1}$, optimally exploited; (c) E above +10% of $E_{0.1}$ to below $E = E_{0.1}$, overexploited; and (d) E equal to or above $E_{0.5}$, highly overexploited. E values were also compared with predicted E_{max} (exploitation rate, which produces maximum yield) to discern if the stock's exploitation level is beyond the maximum sustainable yield level.

Beverton and Holt's relative yield per recruitment (Y/R) and relative biomass-per recruitment (B/R) as a function of E (exploitation rate), $E_{0.1}$ (exploitation rate value where slope or marginal increase in Y/R with increasing E is 1/10 of that at E = very near-zero levels), $E_{0.5}$ (value of E under which the stock has been reduced to 50% of its unexploited biomass), and $E_{\max}$ of each species was estimated using the Beverton and Holt Analysis facility through knife-edge selection procedure in FISAT II.

2.3.2 Catch and species composition

Apart from recording the three mud crab species, the composition of the other species caught by fish corral, crab pot, and gill net in the bay was listed and identified up to species level. The fishery resources were categorized into fish, invertebrates, and other organisms. The total catch value of each species by gear for the year was computed and ranked from highest to lowest. The percentage composition of the major species was calculated from the total fish production.

2.3.3 Production estimates

Mud crab production estimate was estimated by extrapolation. Total catch for the day in kilograms (TCD) was computed by multiplying the total catch

for the day (C) to a raising factor (RF) equivalent to the number sampled landing sites over total landing for the day. Monthly and annual productions were computed by raising the total catch for the day. Hereunder are the following computations:
(1) Total catch for the day (TCD) = Catch for the day (C) x Raising Factor (RF)
where: RF = number of total landing sites in the bay/ sampled landing sites in the bay
(2) Total catch for the month (TCM) = TCD x RF
where: RF = number of days in a month/sampled days
(3) Total catch for the year (TCY) = TCM x RF
where: RF = number of months in a year/sampled months

2.3.4 Catch per unit effort (CPUE)

The major fishing gears used in the bay were identified, and the catch composition of each gear was determined. Catch per unit effort (CPUE) was expressed as kilogram per hour. The CPUE was computed by taking the average catch for the day per gear. The annual mean CPUE was obtained by the summation of the monthly crab harvest over the summation of the number of crab days in a month per year.

2.4 Reproductive biology

Specimens of the three mud crab species were collected monthly throughout the two years (March 2017 to March 2019) from the seven sampling areas for reproductive biology analysis. The collected crab sub-samples from fish corral, crab pot, and gill net were sorted out according to their minimum and maximum size ranges. Gonad examination followed standard protocols (Jimenez et al. 2009), but before dissection, the carapace length (cm) and total body weight (g) of an individual mud crab were recorded. Dissection was done by opening the abdominal cavity of freshly collected individuals to determine the degree of gonad maturity through visual examination of the gonad in fresh individuals.

2.4.1. Gonadal maturity determination and spawning season

The degree of gonad maturity stages was determined by visual examination of male and female gonads based on the four-point gonad maturity scale and was assigned as immature (stage I), initial and final maturity (stage II), ripe (stage III), and spent (stage IV), according to the vascular irrigation intensity, color, and percent volume of abdominal cavity occupied by gonads. Seasonal distribution of gonads by maturity stages was determined monthly, and the overall percentage frequencies observed were used to indicate the seasonal distribution of the gonad maturity stages. The average duration for the spawning season was identified as the time when at least 50% of the adult population has reached maturity.

2.4.2. Gonadosomatic index

Gonadosomatic index (GSI) indicates the percentage of the crab's weight used in egg production and used as an indicator of when crabs are about to spawn (Rasheed and Mustaquim 2010). The gonads were removed and weighed to the nearest 0.01 g using a digital electric weighing scale. Only female gonads in stage III were used in the analysis to verify the strength of spawning during the reproductive months. The GSI was computed as follows:

$$GSI = \frac{\text{Gonad Weight}}{\text{Body Weight}} x100$$

3. RESULTS

3.1 Population parameters

3.1.1 Growth, fishing mortality, and natural mortality

The three mud crab species in Panguil Bay had a growth coefficient (K) of less than 1.0. Respective male and female K values for the three species were 0.6 and 0.6 for *S. tranquebarica*, 0.5 and 0.6 for *S. olivacea*, and 0.7 and 0.6 for *S. serrata* (Table 1). Length-frequency histograms with growth curves are shown in Figure 2. The smallest individuals of all three species seemed to recruit around September and October.

Total (*Z*), natural (*M*), and fishing (*F*) mortality estimates for the three species and by sex showed that mud crabs in Panguil Bay had *F* values greater than *M* values (Table 1; Figure 3). Z values were greatest in *S. serrata* followed by *S. olivacea* and lowest in *S. tranquebarica*. Except for female *S. tranquebarica*, which had Z value greater than that of female *S. olivacea*, the same trends were observed for M and F with values of female *S. tranquebarica* greater than those of *S. olivacea* for both sexes.

Table 1. Summary of the population parameters of the three mud crab species per sex in Panguil Bay, 2017-2019. The meaning of parameters is in the text.

Species	Sex	$L\infty$ (cm)	K (yr^{-1})	Z (M+F)	M (Z-F)	F (Z-M)	E (F/Z)	NRP
S. tranquebarica	Male	11.5	0.6	3.6	1.8	1.8	0.5	2
	Female	11.7	0.6	3.8	1.8	2.1w	0.5	2
S. olivacea	Male	10.9	0.5	4.3	2.0	2.3	0.6	2
	Female	11.4	0.6	5.4	2.6	2.7	0.5	2
S. serrata	Male	12.3	0.7	4.3	2.0	2.3	0.6	1
	Female	12.9	0.6	5.4	2.6	2.7	0.6	1

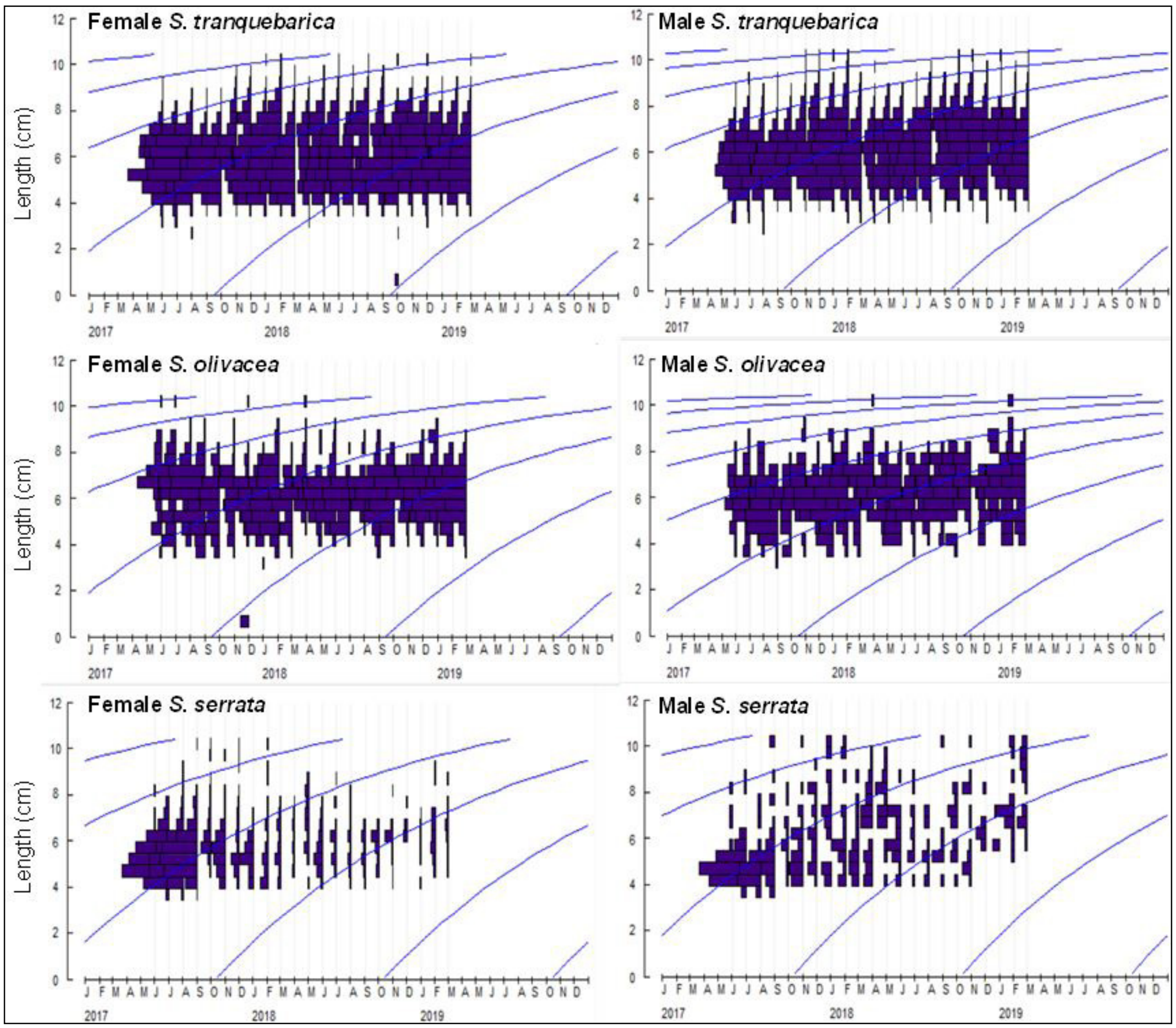


Figure 2. Length-frequency distribution output from FISAT II with superimposed growth curve by sex of the three mud crab species in Panguil Bay (2017-2019).

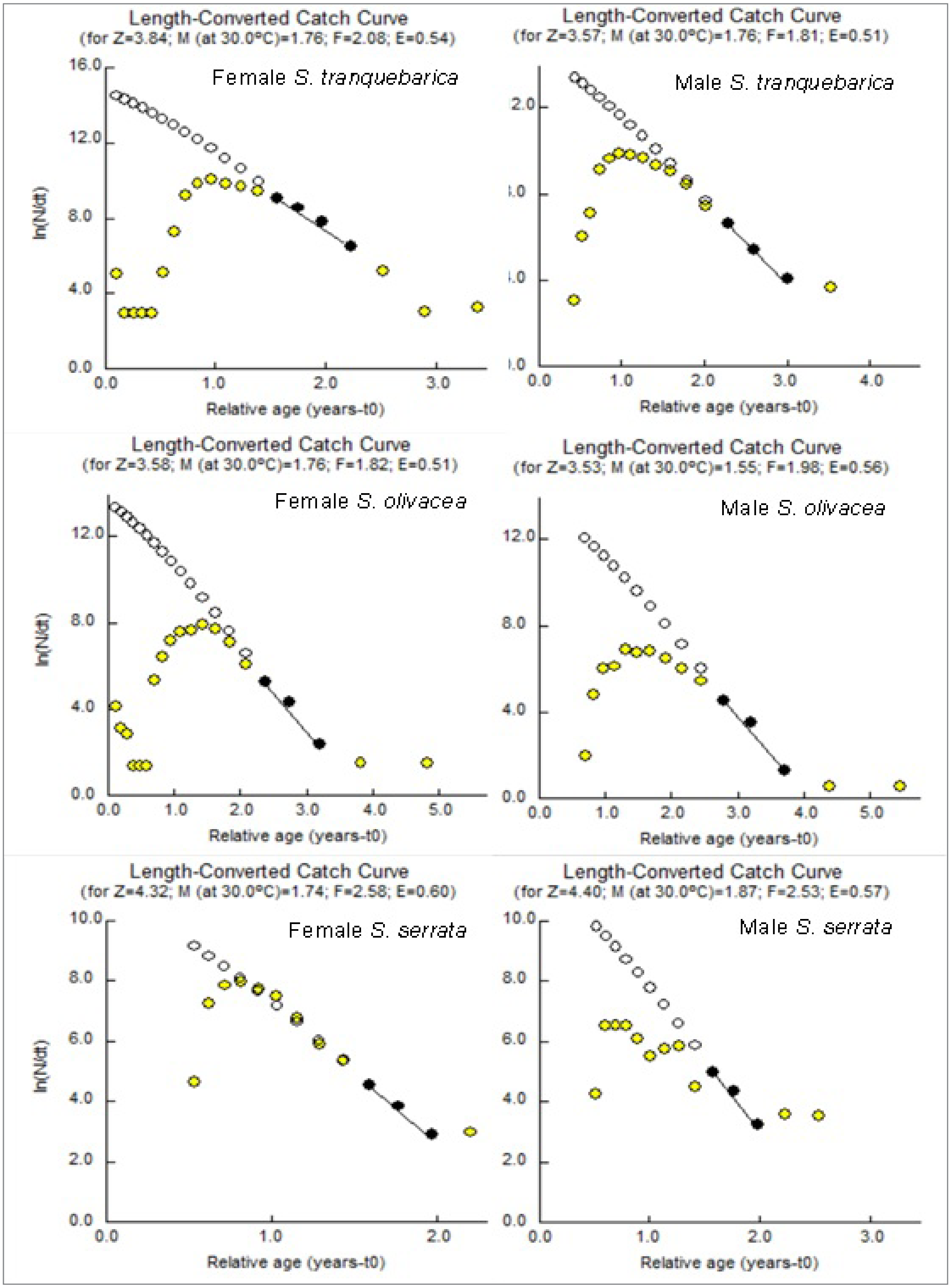


Figure 3. FISAT II output of linearized length-converted of catch curve by sex of the three mud crab species in Panguil Bay (2017-2019). Also shown are the derived values of total mortality (Z), natural mortality (M), fishing mortality (F), and exploitation rate (E) of the three species.

3.1.2 Exploitation rate

Exploitation rates (E) of the three mud crab species in Panguil Bay were greater than 0.50 (Table 1; Figure 3). The highest E values for both sexes were observed in *S. serrata*, while those for *S. tranquebarica* and *S. olivacea* were quite similar. Except for male *S. tranquebarica*, male individuals for the other two species showed greater E values than females. Predicted E_{max} values were greater for *S. olivacea* (0.60-0.64) and S. serrata (0.60-0.66) than those for *S. tranquebarica* (0.46-0.49) (Table 2). E values were slightly above E_{max} values for *S. tranquebarica*, while *E* values were slightly below E_{max} values for *S. olivacea* and *S. serrata* (Table 2).

Table 2. Summary of Beverton and Holt's analysis of yield predictions of the three mud crab species per sex in Panguil Bay, 2017-2019. Similar *E* values are included for direct comparison with E_{max}. The meaning of parameters is in the text.

Species	Sex	L_c / L_∞	*M/K*	$E_{0.1}$	$E_{0.5}$	E_{max}	*E (F/Z)*
S. tranquebarica	Male	0.235	3.0	0.412	0.282	0.505	0.5
	Female	0.231	3.0	0.407	0.279	0.493	0.5
S. olivacea	Male	0.293	4.0	0.520	0.309	0.639	0.6
	Female	0.281	4.3	0.520	0.307	0.643	0.5
S. serrata	Male	0.287	2.9	0.504	0.312	0.662	0.6
	Female	0.301	4.3	0.469	0.303	0.575	0.6

3.1.3 Relative recruitment peaks

Recruitment of the three species differed in the number of peaks, but major peaks occur from June to October for the three species (Figure 4). Both *S. tranquebarica* and *S. olivacea* showed major and minor pulses of recruitment. Entry into the population of the young batch of mud crab was from June to August for female *S. tranquebarica* while June and October for male (Figure 4). *S. olivacea* female recruitment was in August and October. In contrast, the male occurrence was in August and September. Both sexes of *S. serrata* showed only one major pulse, with young recruits occurring in June.

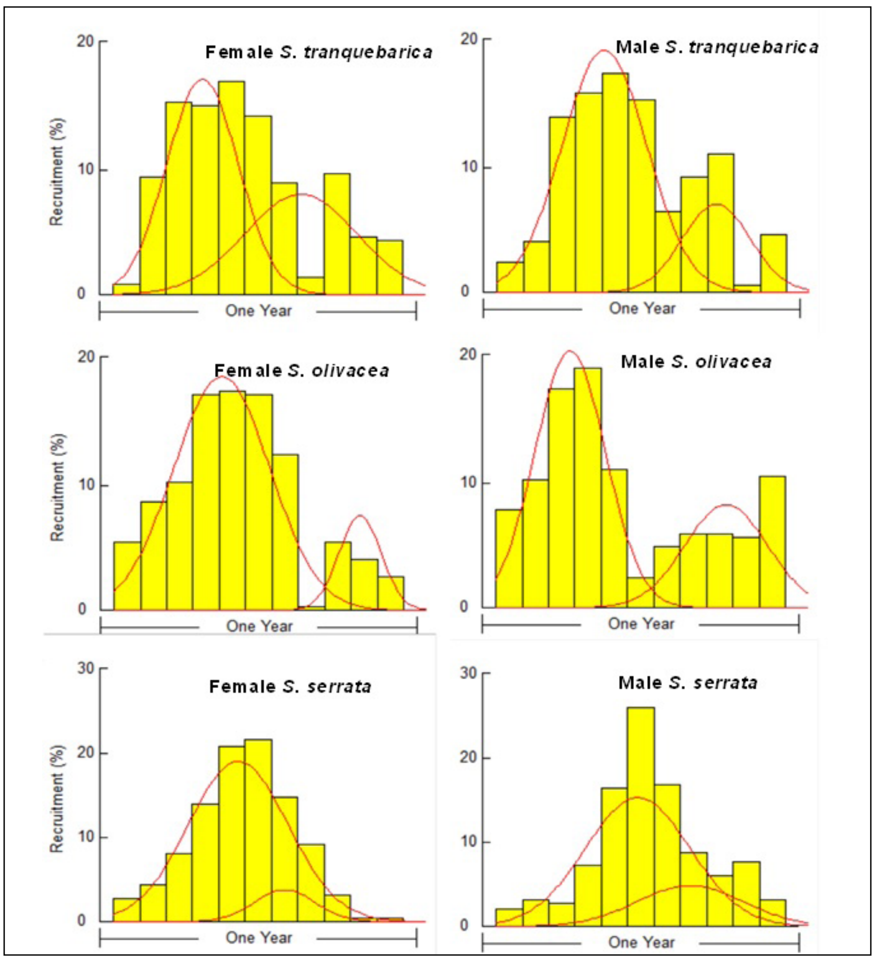


Figure 4. Recruitment proportion by sex of the three mud crab species in Panguil Bay in one year.

3.2 Inventory of fisherfolk fishing boat and gears

3.2.1 Fishing boat and gear

There were 1,419 units or 70.4% of motorized fishing boats, and non-motorized boats contributed 596 units or 29.6% of the total boats involved in the mud crab fishery in Panguil Bay (Table 3). Basically, the high number of fishing boats had a corresponding high number of fisherfolk in the bay. A total of 15 types of fishing gear were recorded being used to catch mud crabs (Table 4). These include fish corral, crab pot, gill net, push net, crab lift net, cast net, filter net, scoop net, single hook and line, multiple hook and line, beach seine, bottom set long line, fish pot, spear gun, and a few modified fishing gears. Fishing gears commonly used for mud crab fishing were; fish corral, crab pot, crab lift net, and gill net. We recorded a total of 85 MT of the three mud crab species captured by these three major gears throughout this study. For all fishing gears, the total landed catch recorded was 103 MT. However, we were not able to establish a correlation between major gears and boat census data.

Table 3. Distribution of fishers and fishing boats among 7 mud crab sampling sites around Panguil Bay in 2017-2019.

Municipality/Province or City	Number of fishers	Numbers of Boats		Total
		Motorized	Non-motorized	
Aurora, Zamboanga del Sur	258	212	79	291
Baroy, Lanao del Norte	375	307	68	375
Bonifacio, Missamis Occidental	271	206	85	291
Kapatagan, Lanao del Norte	167	82	96	178
Kolambugan, Lanao del Norte	53	35	38	73
Lala, Lanao del Norte	381	266	175	441
Tangub, Missamis Occidental	343	311	55	366
Total	**1,848**	**1,419**	**596**	**2,015**

Table 4. Fishing gear and its total mud crab production in Panguil Bay (2017-2019).

Fishing Gear	Total catch (kg)	Metric Tons
Fish corral	50,816.02	50.82
Crab pot	17,269.27	17.27
Gill net	16,915.15	16.92
Push net	7,227.79	7.23
Crab lift net	2,777.78	2.78
Cast net	2,699.05	2.70
Modified	2,363.16	2.36
Filter net	2,184.38	2.18
Scoop net	243.41	0.24
Single hook and line	142.46	0.14
Multiple hook and line	139.85	0.14
Beach seine	110.40	0.11
Bottom set long line	54.35	0.05
Fish pot	6.52	0.01
Spear gun	6.50	0.01
Total	**102,956.09**	**102.96**

3.3 Catch species composition associated with the mud crab fishery

3.3.1 Catch Composition

In terms of biomass, the most abundant commercially exploited species in Panguil Bay are invertebrates with a total contribution of 81%, while finfish and mollusks contributed only 19% and 10%, respectively. Mud crab comprised 42% of these exploited species of invertebrates. Penaeid shrimps, *Penaeus monodon*, *P. merguiensis*, and *Metapenaeus ensis* contributed 22%, while bivalve mollusks contributed 11%, finfishes 9%, and other crustaceans 6%. Mud crab *S. tranquebarica, S. olivacea,* and *S. serrata* were the common species caught by the major fishing gears (mainly stationary fishing gears), namely fish corral, crab pot, and gill net. In fish corrals, the ten major species caught were the shrimps *M. ensis* and *Penaeus merguiensis*, the mudcrab *S. tranquebarica,* and finfish species *Sardinella lemuru, Arius maculatus, Leiognathus equulus,* Gobiid (Bonog), *Siganus sp*., and *Ambassis* sp. (Figure 5). In contrast to fish corral, crab pot and gill net gears had fewer species catch composition which included the three mudcrab species (*S. tranquebarica* (51%), *S. serrata* (4%), and *S. olivacea* (18%)), the blue swimming crab *Portunos pelagicus* (19%) and the finfish species *Selar crumenopthalmus* (8%).

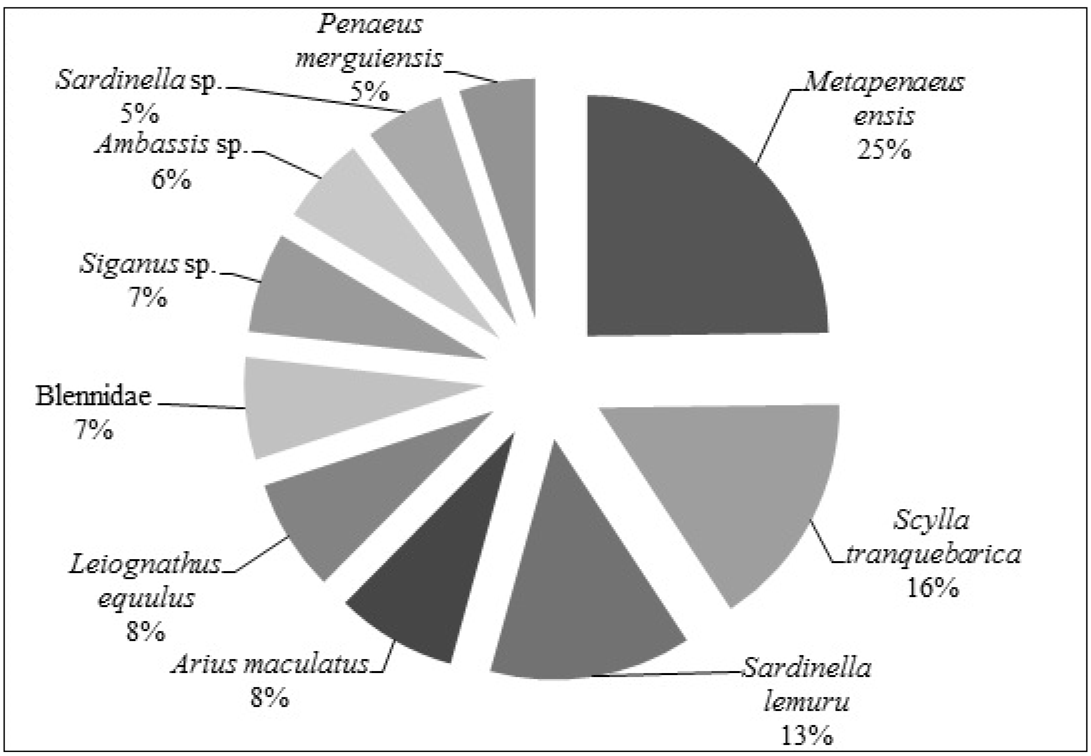


Figure 5. Most abundant species comprising the fish corral catch in Panguil Bay.

3.4 Catch per Unit Effort (CPUE)

Data on the catch per unit effort (CPUE) by gear in Panguil Bay showed that the fish corral gear attained the highest mean CPUE of 3.6 kg per hour with a mean total catch of 8.8 kg per hour. The mean CPUE was lower (1.5 kg per hour and 8.2 kg mean total catch) for the crab pot gear, and the lowest was observed in the gill net with approximately 0.8 kg per hour with a total catch of 4.7 kg (Figure 6).

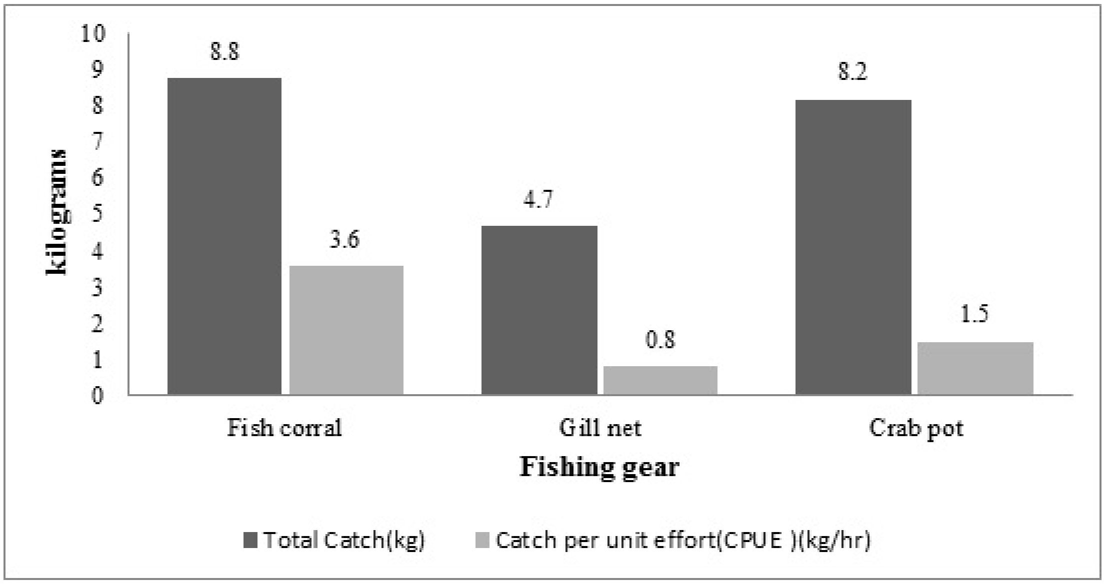


Figure 6. Catch and catch per unit effort for mud crabs in Panguil Bay (2017-2019).

3.5 Reproductive biology

3.5.1 Sex ratio

The study collected 19,077 female and 16,682 male mud crabs (Table 5). By species and sex, the samples showed that female mud crabs outnumbered to males. The total number of female individuals of *S. tranquebarica, S. olivacea,* and *S. serrata* were 16,060, 2,640, and 377, respectively. Compared to males of the three species, we recorded 15,225, 1,266, and 377 individuals, respectively.

Table 5. Monthly variation in the sex ratio of the three mudcrab species in Panguil Bay (2017-2019).

Month	*S. tranquebarica*				*S. olivacea*				*S. serrata*			
	Female	**Male**	**Total**	**F:M**	**Female**	**Male**	**Total**	**F:M**	**Female**	**Male**	**Total**	**F:Mt**
January	1,819	1,835	3,654	1:1.01	276	132	408	1:4.09	12	13	25	1:1.08
February	2,057	1,864	3,921	1.10:1	318	158	476	2.01:1	24	17	41	1.41:1
March	1,177	1,141	2,318	1.03:1	234	113	347	2.07:1	10	15	25	1:1.50
April	314	326	640	1:1.04	84	69	153	1.22:1	10	12	22	1:1.20
May	564	519	1,083	1.09:1	90	53	143	1.70:1	10	7	17	1.70:1
June	1,182	1,063	2,245	1.11:1	191	97	288	1.97:1	15	15	30	1:1
July	1,532	1,337	2,869	1.15:1	228	97	325	2.35:1	106	36	142	2.94:1
August	1,528	1,225	2,753	1.25:1	198	97	295	2.04:1	53	10	63	5.30:1
September	792	867	1,659	1:1.09	372	139	511	2.68:1	71	25	96	2.84:1
October	2,122	1,903	4,025	1.12:1	279	129	408	2.16:1	10	14	24	1:1.40
November	1,410	1,692	3,102	1:1.20	134	129	263	1.04:1	34	15	49	2.27:1
December	1,563	1,453	3,016	1.08:1	236	53	289	4.45:1	22	12	34	1.83:1
Total	**16,060**	**15,225**	**31,285**	**1.05:1**	**2,640**	**1,266**	**3,906**	**2.09:1**	**377**	**191**	**568**	**1.97:1**

3.5.2 Gonad maturity

A total of 760 mud crab individuals from the three species were dissected for gonadal maturity analysis. The majority of the samples collected in the bay were at initial and final maturity or stage II having 457 individuals. In this stage, samples are abundant in October for females (Figure 7) and in September for males (Figure 8). Female stage III samples had the highest peak in May and August for the three mud crab species. On the other hand, by species and by sex, the high occurrence of male and female stage I samples was observed in May and October for *S. tranquebarica*; May and June for *S. olivacea*; and June and October for *S. serrata*.

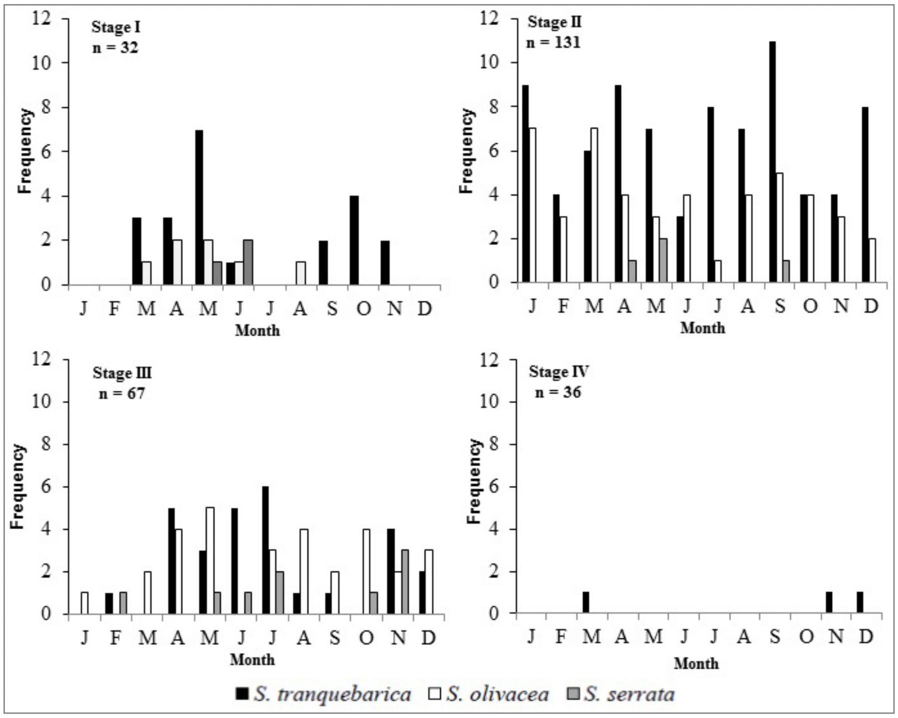


Figure 7. Monthly variation of the female maturity stages of the three mud crabspecies in Panguil Bay, 2017-2019.

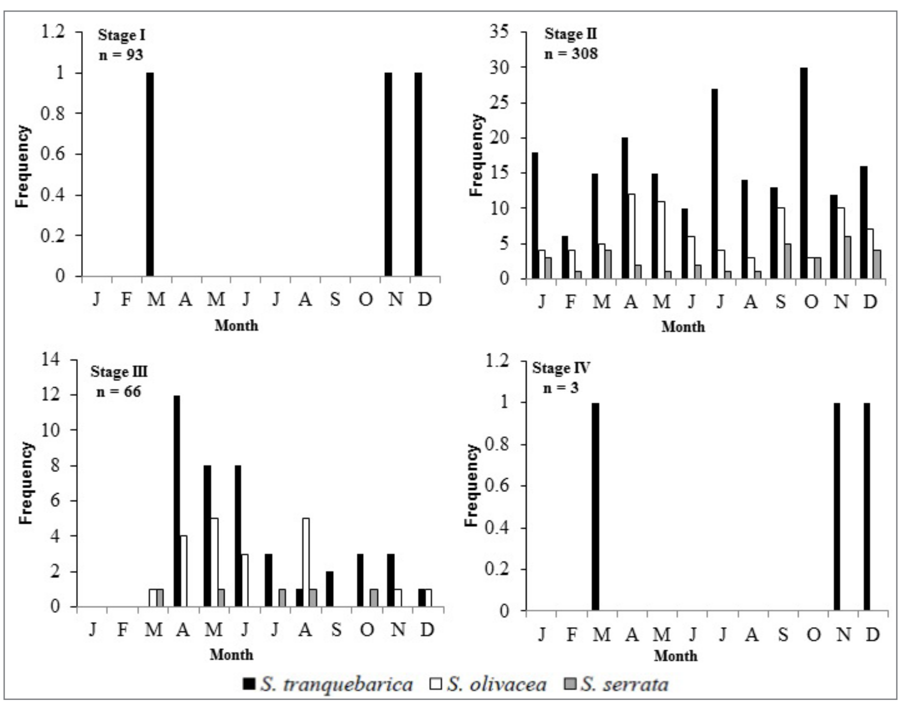
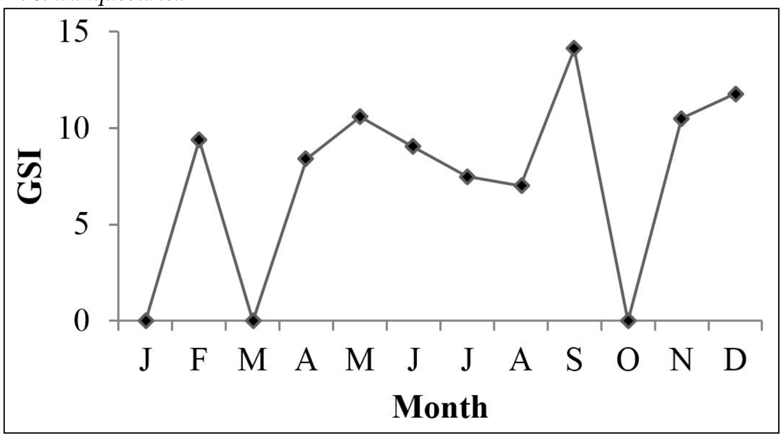


Figure 8. Monthly variation of the male maturity stages of the three mud crab species in Panguil Bay, 2017-2019.

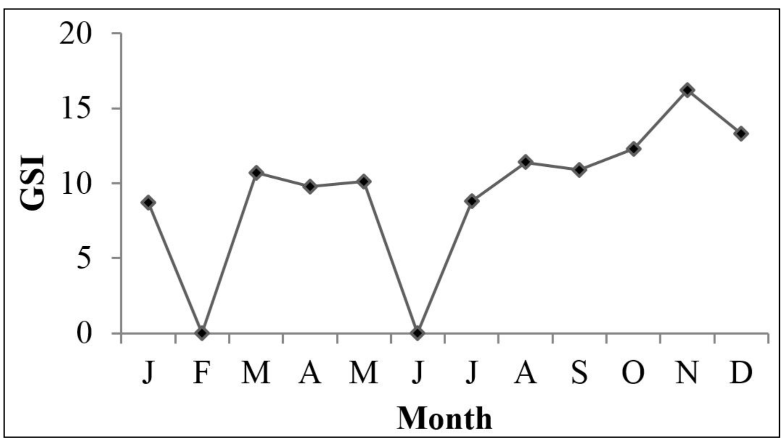
3.5.3 Gonado Somatic Index (GSI)

The monthly mean GSI values indicated that S. olivacea and S. serrata had the same maximum values of 15.1 in November, while S. tranquebarica had 16.2 in September (Figure 9). Additionally, the lowest GSI mean values were in the warm months of April for S. tranquebarica (8) and S. olivacea (8), and May for S. serrata (8.7).

A. *S. tranquebarica*



B. *S. olivacea*



C. *S. serrata*

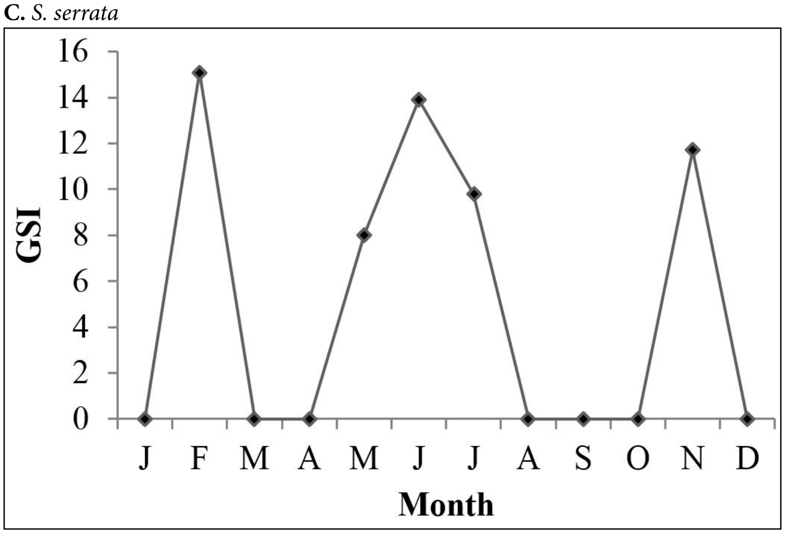


Figure 9. Monthly Gonado Somatic Index (GSI) of female stage III of *S. tranquebarica, S. olivacea,* and *S. serrata.*

4. DISCUSSION

Population parameters. One of the methods used in fisheries management is the analysis of catch and effort data over a period of time (Sparre and Venema 1998; Zafar et al. 2006; Ward et al. 2008). This allows the assessment of the status of present exploitation levels of targeted fisheries species (Zafar et al. 2006). Viswanathan et al. (2016) reported that the mud crab males (*K* = 0.76 year-1) grow slower than females (*K* = 0.86 year-1). However, Mirera and Mtile (2009) reported no significant difference in growth rate between males and females. These mixed results on K values are shown in the three species in Panguil Bay, with male and female *S. tranquebarica* showing similar values, but female *S. olivacea* showing higher value than males, and the opposite for *S. serrata*. These differences could be attributed to ecological settings such as food availability, predation (natural mortality) and competition, and the level of fisheries exploitation (fishing mortality). The contribution of ecological factors against fisheries exploitation to growth rates of both sexes of the three species needs further investigation.

Total mortality (*Z*) and fishing mortality (*F*) are indicative of the exploitation of the species. The study's outcome showed that all F values are greater than natural mortality (*M*), suggesting that the three mud crab species in Panguil Bay contribute to a major invertebrate fishery. In particular, the three species are highly overexploited ($E > 0.50$) as *E* values for all three species ranged from 0.51 to 0.60 (Yudiati et al. 2020). *S. serrata* showed the highest *E* and *Z* compared to the other two species, which had similar values for both parameters. Consequently, *S. serrata* has shown the smallest population size compared to the other two species in Panguil Bay. The supposedly 'giant' mud crab *S. serrata* has only registered a maximum carapace length of 10.4 cm in Panguil Bay compared to a maximum of 13.3 cm in the Indonesian population (Widigdo et al. 2017) and a record length of 28 cm (Ng 1998). Since *E* values are still slightly below or above the E_{max} values, exploitation is already hovering around the maximum sustainable yield level, and urgent fishing effort reduction is needed.

Fishing boat and gear. The number of fishing boats decreased from 5,001 units in 2005, as reported by Jimenez et al. (2009), to 2,015 units in the present study. On the other hand, by boat type, the number of motorized boats (1,419 units) was higher than non-motorized boats (596 units). Jimenez et al. (2009) reported 1,343 units of motorized boats, suggesting an increase of 5.36% in the number of motorized boats from the past assessment. The sudden increase in motorized fishing boats can be due to the fact that the Bureau of Fisheries and Aquatic Resources (BFAR) recently implemented the free boat program where free motorized boats were given to their target beneficiaries. Incidentally, according to interviewees, these boats were used in the filter net gear operation, although there is a law that prohibits this particular fishing gear in the bay (Dickson 2009). However, the small increase in the number of motorized boats should not contribute substantially to increased landed catch of mud crab that we recorded, but more of the increased frequency of use of fish corrals, crab pots, and gill net, the three most efficient gears in catching mud crabs.

CPUE. The total landed catch decreased from 201.1 MT (Jimenez et al. 2009) to 103.0 MT in the present study. The CPUE per hour increased as the number of fishing boats and gears increased, and the corresponding total production in Panguil Bay has decreased. Precisely, fish corral contributed the highest total catch of all three Scylla species production. Our observations on the total current production in Panguil Bay can be attributed to several factors, namely, overfishing due to excessive effort, poor recruitment of significant stocks, and declining environmental quality of the bay (Jimenez et al. 2009). However, another important reason for the progressive decline in the bay's mud crab and other fisheries is the half-hearted resource management efforts implemented by many coastal Local Government Units (LGUs) around the bay, except for Kolambugan and Kapatagan that have been actively enforcing fishery laws (Jimenez et al. 2009). Reduction of the mangrove habitat by 20,000 to 30,000 sq km from 1990 to 2010 (Long et al. 2014) and degradation of seagrass beds and coral reefs in the Panguil Bay (Jimenez et al. 2009; Roxas et al. 2009) may also be contributory to the decline.

Reproductive biology. The differences in size at sexual maturity among the population of the same crab species also may be attributed to variation in molt increment and the number of molts (Rasheed and Mustaquim 2010). In the present study, the incidence of high maturation for female mud crab at maturity stage III was observed in the wetter months of August to October in Panguil Bay (Metillo et al. 2015). The result is the same as in the past study conducted by Heasman et al. (1985) and Le Vay (2001). They specified that in tropical populations, a higher maturation always appears during the wet season with high rainfall, which is consequent to high productivity in coastal waters. Mud crabs are known to spawn during wetter months (Yudiati et al. 2020), and the present study provides evidence of high numbers of mature individuals, high GSI values, and growth pattern from length-frequency analysis supporting a spawning season of the three species of mangrove crabs during wetter months in Panguil Bay. These findings may be a basis for a possible policy brief reducing the catch of mud crabs from July to October to allow mud crabs to spawn.

5. CONCLUSION

The stock assessment of the three mud crab species in Panguil Bay from March 2017 to March 2019 revealed a sudden increase in the number of motorized boat units in the mud crab fishery, and a large number of fish corral, gill net, and crab pot. Underwater filter net, "sanggab," the prohibited fishing gear, is still present in the bay. These realities may significantly contribute to the decline in the bay's annual production of the mud crab species.

This study's total production estimate is lower by 50% compared to values reported in 2009, and we primarily attribute this to increased fishing effort. Stock assessment analysis data reinforce this finding as evident in much greater fishing mortality than natural mortality. Thus, the mud crab fishery is considered highly overexploited (E value is greater than $E_{0.5}$) in Panguil Bay due mainly to the high fishing effort using fish corral and gill net. Since stocks are already hovering around maximum sustainable yield levels (E_{max}), immediate reduction in fishing effort and stock rebuilding and enhancement effort are urgently needed. Reproductive biology results suggest spawning during the high rainfall months, and reduction in the catching of spawner mud crabs during these months is highly recommended. The present assessment provides information useful to ecosystem-based management of the mud crab fishery in Panguil Bay.

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AUTHOR CONTRIBUTIONS

Jumawan CQ: Conceptualization, Methodology, Writing-Original draft preparation, Supervision. **Metillo EB:** Conceptualization, Methodology, Writing-Original draft preparation, Supervision, Data analysis, Writing-Reviewing and Editing, Answering Reviewers Comments and Suggestions. **Polistico JP:** Data curation, Visualization, Investigation, Writing-Reviewing.

CONFLICT OF INTEREST

There is no conflict of interest to declare.

ETHICS STATEMENT

No animal or human studies were carried out by the authors.

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