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ARTICLE

Population dynamics of blue swimming crab (*Portunus pelagicus*) in Samar, Philippines

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ABSTRACT

The blue swimming crab (*Portunus pelagicus*) is an economically and ecologically important species in Indo-Pacific coastal fisheries. In Samar, Philippines, declining catches have raised concerns about the sustainability of this resource due to increasing fishing pressure and habitat disturbance. This study assessed the population dynamics of *P. pelagicus* from February to November 2023 across three municipal fishing grounds in Samar. A total of 4,131 crabs were sampled from artisanal landings, and their carapace width (CW) was measured. Length-frequency data were analyzed using the Bhattacharya method and the ELEFAN I routine in FISAT II, using the von Bertalanffy Growth Function, to estimate growth, recruitment, and mortality parameters. Results showed that the population was dominated by intermediate size classes (81–110 mm CW), while larger individuals (>120 mm CW) were relatively scarce, indicating a truncated population structure. Growth analysis estimated a growth coefficient $K = 0.92\ yr^{-1}$, suggesting rapid growth. Recruitment occurred year-round with distinct peaks in June (16.43%) and September (13.44%). Mortality estimates were $Z = 2.93\ yr^{-1}$, $M = 1.08\ yr^{-1}$, and $F = 1.85\ yr^{-1}$ ($R^2 = 0.8932$), resulting in an exploitation rate (E) of 0.63. Because E exceeded the commonly used optimal threshold of 0.50, the results indicate substantial fishing pressure on the stock. These findings emphasize the need for management interventions, including seasonal closures during peak recruitment periods, enforcement of minimum size limits, and improved gear selectivity, to maintain reproductive capacity and ensure the long-term sustainability of *P. pelagicus* fisheries in Samar.

INTRODUCTION

The blue swimming crab (*Portunus pelagicus*) is a commercially valuable crustacean species widely distributed throughout the Indo-Pacific region, including the Philippines (Kunsook et al., 2014). Known for both its economic significance and ecological function, *P. pelagicus* contributes significantly to the livelihoods of small-scale fishers and the country's seafood export industry, particularly in coastal areas such as Samar (Cabrales et al., 2015; Mesa et al., 2017). The Food and Agriculture Organization (FAO, 2020) has recognized the rising global demand for blue swimming crab (BSC), further strengthening its status as an essential fisheries commodity in tropical countries. In the Philippines, from 2019 to 2023, BSC production averaged 28,089.93 metric tons (MT), with Eastern Visayas accounting for 7.47% or 2,097.4 MT of this average output. Notably, 69.21% of this regional production originated from the municipal waters of Samar (PSA, 2018; PSA, 2020; PSA, 2022; PSA, 2024). However, this productive trend is increasingly under threat. Recent data indicate a substantial decline in BSC catch in Samar, dropping from 1,787.95 MT in 2016 to roughly 1,099 MT in 2019, which is equivalent to a 38.5% decrease in just four years (PSA, 2018; PSA, 2020). A comparable downward trend in BSC landings was observed across various Philippine regions between 2019 and 2023. Notably, the Bicol region experienced a significant 62.35% reduction in production, falling from 5,524 MT in 2019 to 2,080 MT in 2023 (PSA, 2024).

Several studies have attributed this downward trajectory to intensified fishing pressure, habitat degradation, and the multifaceted impacts of climate change (Shafeeq et al., 2024; Kurnia & Boer, 2014; Naimullah et al., 2024). De la Cruz and colleagues (2015) emphasized that the growing number of fishers in municipal waters has exacerbated overfishing, which in turn alters the species' growth, recruitment, mortality, and size structure, and compromises the sustainability of local stocks. Such changes, particularly in growth, recruitment, and mortality, significantly affect size structure and population abundance, emphasizing the need for science-based conservation strategies.

The BSC is considered a short-lived species, typically reaching sexual maturity within 10 to 14 months, a life-history trait that strongly influences its population dynamics and vulnerability to fishing pressure (Ernawati et al., 2017; Mehanna et al., 2013). Because of its rapid growth, early maturation, and relatively high natural mortality, the population structure of *P. pelagicus* can

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change quickly in response to environmental variability and exploitation. Recruitment success in any given season therefore plays a critical role in sustaining the population, as each cohort contributes to the fishery for only a short period. Fluctuations in recruitment, growth, or survival can rapidly translate into changes in abundance, catch rates, and size structure within a single year (Kunsook et al., 2014; Kangas, 2000).

In addition, the BSC is primarily distributed in shallow coastal and estuarine waters, where populations are often concentrated in nearshore habitats that are easily accessible to small-scale and municipal fisheries. This restricted distribution, combined with a short life cycle, heightens the sensitivity of *P. pelagicus* populations to localized overfishing and habitat degradation. Population dynamics parameters such as growth, recruitment, and mortality therefore provide essential information for fisheries management, as even short-term increases in fishing effort can have immediate impacts on stock sustainability. Understanding these dynamics is particularly important in tropical fisheries, where continuous recruitment and overlapping cohorts can mask early signs of population decline if not carefully monitored (De la Cruz et al., 2018; Pauly, 1984).

Given these biological characteristics, population dynamics studies are fundamental to the sustainable management of BSC fisheries. Accurate estimation of growth rates, recruitment patterns, and exploitation levels allows managers to design adaptive measures, such as seasonal closures, size limits, and effort controls, that are responsive to the species' rapid turnover and limited spatial distribution. Incorporating life-history traits into management frameworks is therefore essential to balancing economic benefits with the long-term conservation of *P. pelagicus* stocks.

Past research, including studies by Kunsook et al. (2014) and De la Cruz et al. (2018), stressed the importance of understanding population dynamics to formulate effective conservation measures. Parameters such as size distribution, growth rates, and mortality estimates not only inform management decisions but also help prevent overexploitation. While countries like Indonesia, Thailand, Taiwan, and India have conducted extensive studies on *P. pelagicus* population dynamics, similar research remains scarce in the Philippine context, especially in Samar. This knowledge gap hinders the implementation of management interventions such as seasonal closures or size limits, which often lack the empirical backing required for effectiveness (Kunsook et al., 2014).

Recent studies have expanded our understanding of the reproductive biology, growth, and exploitation status of *P. pelagicus*. Haputhantri and colleagues (2022) investigated fecundity and feeding ecology and found that fecundity positively correlated with carapace width and body weight. These findings illustrate the direct linkage between size structure and reproductive output. When fishing pressure disproportionately removes larger females, the population's fecundity declines, undermining recruitment potential.

Yulianto and colleagues (2024) studied East Lampung coast fisheries using Spawning Potential Ratio (SPR) analysis. They found an SPR of only 19%, well below the biological reference limit of 20% and target of 50%, implying substantial fishing pressure and compromised reproductive capacity; the average caught size (Lc50) was 109.54 mm, suggesting removal of suboptimal size classes before contributing sufficiently to spawning (Yulianto et al., 2024). Such low Spawning Potential Ratio (SPR) reflect how truncated size structure directly impairs recruitment by reducing the proportion of mature spawners.

Juvenile BSC rely heavily on mangrove and seagrass ecosystems for shelter and development. Unfortunately, these habitats are increasingly compromised by aquaculture expansion and coastal development (Cuenca et al., 2015; Mizerek et al., 2011). Moreover, climate-related stressors, such as ocean acidification, rising sea temperatures, and fluctuations in salinity and oxygen levels, may negatively affect larval survival and reproductive success (Przeslawski et al., 2015; Talpur & Ikhwanuddin, 2012; Jeeva et al., 2017). Therefore, protecting and restoring these habitats should be included in management recommendations to support sustainable BSC populations.

Data from Sri Lanka and Thailand further highlight these trends. The BSC fishery off the northern coast of Sri Lanka is experiencing overexploitation ($E > 0.5$) driven by gradual post-war increases in fishing effort ('effort creep'), high market demand, and socio-cultural constraints such as caste-based gear and fishing ground preferences that increase the capture of immature crabs (Digamadulla & Croos, 2023). The Crab Bank Project in Thailand, aimed at restoring stocks through larval release, illustrates a conservation interventions; yet, larval dispersal modeling revealed uncertainties around settlement success due to habitat variability (Onsri et al., 2024).

Studies on the population dynamics of *Portunus pelagicus* in various coastal areas reveal consistent patterns of growth and exploitation. Growth parameters (CW_∞ and K) vary across locations, with values ranging from 152.04–173.04 mm and 0.45-1.0 yr^{-1}, respectively (Hamid & Wardiatno, 2015; Sawusdee & Songrak, 2011; Khowhit, 2020). Mortality rates, including total (Z), natural (M), and fishing (F) mortality, were reported across studies, with F generally exceeding M. Exploitation rates (E) consistently indicate substantial fishing pressure, ranging from 0.61 to 0.82 (Hamid & Wardiatno, 2015; Sawusdee & Songrak, 2011; Khowhit, 2020). Recruitment patterns were found to be continuous with peak periods in March to July (Khowhit, 2020). Stock assessments suggest the need for reducing fishing effort to ensure sustainability (Sawusdee & Songrak, 2011). These findings highlight the importance of effective management strategies for *P. pelagicus* populations across different regions.

Despite the ecological and economic importance of the BSC in tropical small-scale fisheries, empirical information on its population dynamics in Samar remains limited. The lack of local data on key biological parameters, such as population structure, recruitment patterns, and fishing pressure, restricts the development of effective, site-specific management policies. Considering the documented decline in BSC landings in Samar and the evidence of overexploitation in nearby regions, generating reliable local data is essential to support informed fisheries management and promote the long-term sustainability of the resource.

Objectives

To address this gap, the present study investigated blue swimming crab (*Portunus pelagicus*) population dynamics in Samar from February to November 2023. The objectives are to:

1. Examine the size-class distribution to detect shifts or truncation patterns.
2. Estimate growth parameters using the von Bertalanffy growth function.
3. Analyze recruitment patterns using length-based methods.
4. Determine mortality rates (total, natural, and fishing) and exploitation rate.

These study aims to generate baseline data to support fisheries management in Samar, particularly for interventions such as size limits, gear restrictions, seasonal closures, and habitat protection.

MATERIALS AND METHODS

Sampling and Sampling Sites

Crab samples were collected monthly from February to November 2023 from three municipal fishing grounds along Maqueda Bay, Samar, Philippines: (1) near Motiong, Samar (11°45'5.64"N, 124°59'29.61"E), (2) Brgy. Bioso, Zumarraga, Samar (11°42'29.73"N, 124°50'40.47"E), and (3) near Brgy. Mancares, Tarangnan, Samar (11°51'59.79"N, 124°45'42.72"E) (Figure 1). These sites represent common artisanal fishing areas within Maqueda Bay with a depth range of approximately 3–5 meters. Sampling was conducted through collaboration with local fishers who used traditional crab lift nets locally known as *bintol* or *panggal*. For each monthly sampling event, crabs landed from the three sites served as replicate samples representing the spatial distribution of the catch. Each specimen was identified and classified by sex, and the carapace width (CW) was measured to the nearest 0.01 mm using a Vernier caliper across the widest lateral points of the carapace. Undersized and gravid individuals were measured and recorded, after which they were immediately released back to the capture site to minimize impacts on the local crab population.

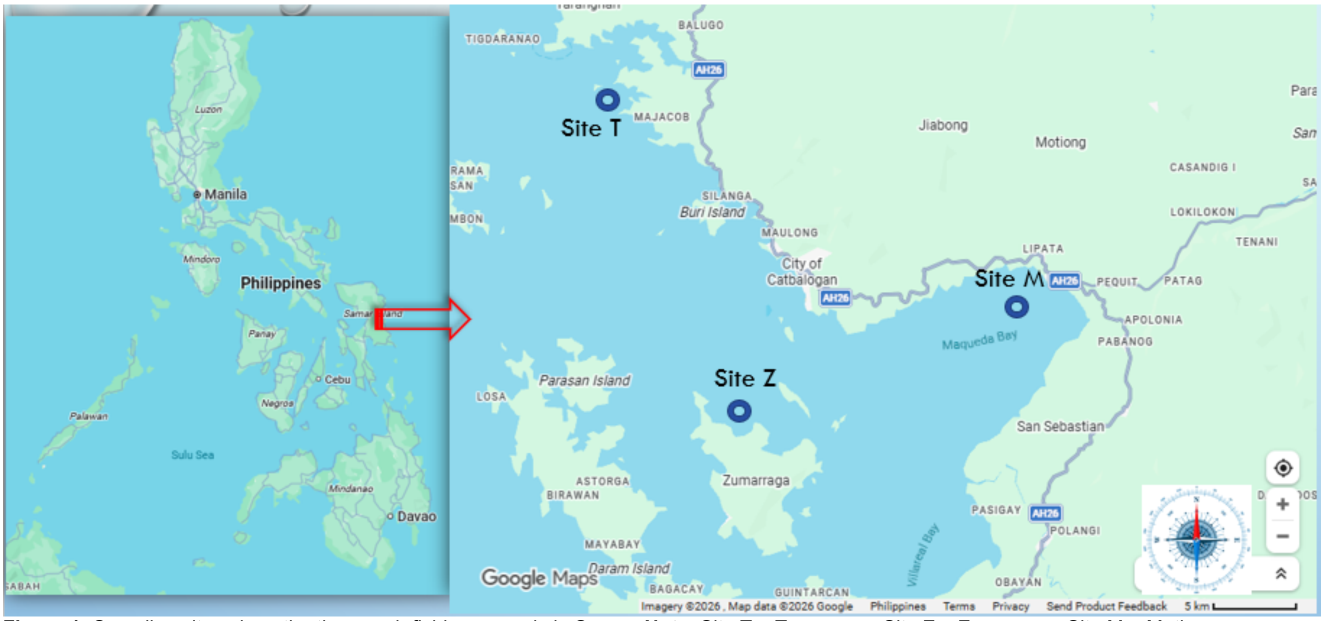

Figure 1: Sampling sites along the three crab fishing grounds in Samar. **Note**: Site T = Tarangnan; Site Z = Zumarraga; Site M = Motiong.

Size Class Distribution

Carapace widths (CW) of male and female crabs from each collection period were tabulated to determine the size class frequency distribution in 10-mm class increments, ranging from a minimum CW of 61 mm to a maximum of 141 mm. Ten-millimeter bins are commonly used for population dynamic models and length-frequency analysis in ELEFAN or Bhattacharya's method (Wang et al., 2020). These data were used to estimate population size structure, growth parameters, recruitment, and exploitation rates. The Bhattacharya method, implemented in FISAT II (Gayanilo et al., 2005), was used to analyze the length-frequency distributions into normally distributed cohorts.

This statistical approach allows identification of modal progressions corresponding to age cohorts, which is critical for interpreting growth patterns (Mehanna et al., 2013). This can be used to track how the average size (mean carapace width) of a specific cohort shifts over time providing a visual and mathematical record of growth (Kunsook et al., 2014).

Modal Progression Analysis (MPA) in FISAT II is a length-based analytical technique used to estimate growth parameters of fishery species, including crustaceans, by following the movement of cohorts through time using length-frequency data. This method is particularly valuable in tropical or data-limited fisheries, where age determination through otoliths or other hard structures is often difficult or unreliable.

The procedure generally involves three main stages. First, the decomposition of length-frequency distributions is performed to separate a composite size histogram into individual modal groups, each representing a cohort or age group. Two methods are commonly applied in FISAT II. Bhattacharya's Method is a semi-graphical approach that visually separates overlapping normal distributions within the length-frequency data, while NORMSEP uses an iterative maximum likelihood algorithm to statistically partition the distribution into normally distributed components.

The second stage involves identifying and linking the modal means obtained from successive sampling periods. After determining the mean lengths of cohorts for different months, the analyst connects corresponding modes across time. This modal linkage tracks the growth of cohorts as they increase in size between sampling intervals, effectively reconstructing cohort progression within the population.

Finally, the linked modal progression data are used to estimate growth parameters, typically within the framework of the von Bertalanffy Growth Function. The slope of the regression line fitted through the sequential modal means represents the average growth increment of the cohort, which corresponds to the population's mean growth rate. These growth increments can then be stored and analyzed similarly to growth data obtained from tagging or mark-recapture studies, providing a practical alternative for estimating growth in species where direct aging methods are not feasible.

Growth Parameter Estimation

The growth and population parameters in this study were estimated using the FAO–ICLARM Stock Assessment Tools II (FISAT II), a widely recognized software package developed for the analysis of length-frequency data in fisheries, particularly in data-limited tropical settings (Gayanilo et al., 2005). FISAT II integrates several analytical procedures that allow the estimation of growth, recruitment, mortality, and exploitation rates without relying on age-based data, making it especially suitable for crustacean species such as *Portunus pelagicus*.

Within FISAT II, the Electronic Length Frequency Analysis (ELEFAN I) module was used to estimate the parameters of the von Bertalanffy Growth Function (VBGF) (Sparre & Venema, 1998; Gayanilo et al., 2005). ELEFAN I is a non-parametric method that fits growth curves to restructured length-frequency distributions by tracking modal progressions over time. The algorithm identifies cohorts by maximizing a goodness-of-fit index (Rn), which measures how well a candidate growth curve aligns with peaks in the length-frequency data (Pauly & David, 1981). This approach is particularly appropriate for tropical crustaceans, which typically exhibit continuous recruitment and overlapping cohorts.

The VBGF was selected because of its strong biological foundation and its suitability for species with indeterminate growth by successive molting. The model describes a nonlinear growth pattern characterized by rapid growth during early life stages followed by a gradual approach to an asymptotic size, closely reflecting the growth characteristics of *P. pelagicus*. Moreover, the VBGF parameters are biologically interpretable and compatible with length-frequency–based analytical techniques, making the model well suited for fisheries assessments in data-limited contexts.

FISAT II also incorporates the ELEFAN I procedure, which refines growth parameter estimates through iterative optimization techniques, and a length-converted catch curve analysis used to estimate total mortality (Z). From this, fishing mortality (F) and exploitation rate (E) were derived using established fisheries equations (Pauly, 1984). Together, these methods provide a comprehensive and robust framework for evaluating stock status and fishing pressure.

In this study, the VBGF was used through the ELEFAN I procedure in FISAT II to estimate the asymptotic carapace width ($CW\infty$) and growth coefficient (K) by fitting modal progressions across monthly length-frequency data. To enhance the robustness of the estimates, the derived growth parameters were compared with values reported in recent regional studies, allowing for cross-validation and consideration of site-specific environmental variability. The VBGF has been widely and successfully applied in studies of *P. pelagicus* and other portunid crabs across tropical regions, demonstrating its reliability in describing growth dynamics and supporting fisheries management (Kunsook et al., 2014; De la Cruz et al., 2018). The consistent validation of this model in related studies supports its suitability for the present research and strengthens the methodological framework for assessing the growth and population dynamics of *P. pelagicus* in Samar.

Estimation of Recruitment
The data on carapace size class distribution for males and females combined were used to estimate recruitment. Recruitment was estimated using the recruitment-pattern subprogram in FISAT II, which generated monthly recruitment proportions. (Gayanilo et al., 2005). In FISAT II, the Recruitment Pattern subprogram is used to examine the seasonality and intensity of new individuals entering a fishery by projecting length-frequency data backward along a one-year time scale. The method uses combined carapace width distributions of males and females and applies growth parameters derived from the von Bertalanffy Growth Function to estimate how long it would take individuals to grow from zero length to their observed size. Each size class is then projected backward in time to infer the likely month of recruitment. To ensure statistical robustness and representativeness, the length-frequency data were pooled monthly, aggregating all samples within each month to smooth out daily sampling noise and emphasize the population's modal structure.

The output expresses recruitment as monthly proportions rather than absolute numbers, indicating the relative contribution of each month to annual recruitment and allowing identification of unimodal or bimodal recruitment peaks. These estimates are considered theoretical because the method assumes that growth follows the VBGF and that mortality remains constant across size classes.

Reproductive and recruitment dynamics were compared qualitatively with observed seasonality in related sites, such as Lasongko Bay, where peak recruitment occurred between June and October (Hamid & Wardiatno, 2015), to assess whether similar temporal patterns emerge in Samar.

Estimation of Mortality and Exploitation
The total mortality (Z) was estimated using a length-converted catch curve in FISAT II (Gayanilo et al., 2005; Pauly, 1984) according to the equation:

$$\frac{\ln N}{\Delta t} = a + bt,$$

where *N* represents the number of crabs within a given size class, Δt denotes the time (in years) required to reach that size class, *t* is the relative age (years), *a* is the intercept, and *b* is the regression coefficient, with total mortality calculated as $Z = -b$.

Fishing mortality (F) and exploitation rate (E) were subsequently estimated following Pauly (1984) using the equations $F = Z - M$ and $E = F/Z$. An exploitation rate below 0.5 ($E < 0.5$) indicates low exploitation rate, whereas a value above 0.5 ($E > 0.5$) suggests high exploitation rate indicative of overfishing. An exploitation rate equal to 0.5 ($E = 0.5$) is considered optimal.

Ethical Considerations
The study adhered to ethical guidelines for marine invertebrate sampling. Handling time was minimized to reduce stress; crabs were measured swiftly and returned promptly. The collection focused on minimizing impact on the population by releasing gravid and undersized specimens. All sampling and research activities were conducted under a special permit from DA-BFAR, ensuring compliance with national regulations and research ethics.

RESULTS AND DISCUSSION

Class Size Distribution of *P. pelagicus*
A total of 4,131 crabs were sampled during the 10-month period starting from February to November. The monthly distribution of sample sizes shows notable variation that may be partly explained by the monsoon season and tidal dynamics, particularly the occurrence of neap tides in April and September. From February to March, sample sizes remained relatively stable (373 and 376, respectively), reflecting normal fishing conditions with adequate tidal currents that facilitate crab movement and increase gear efficiency. In April, however, the sample size declined to 364, which may be attributed to the occurrence of neap tides during this period. Neap tides are characterized by reduced tidal range and weaker water currents, conditions that can limit the movement and foraging activity of BSC and consequently reduce their susceptibility to capture (Spencer et al., 2019; Hewitt et al., 2023).

From May through August, sample sizes increased and remained relatively high (ranging from 419 to 448), suggesting improved fishing conditions associated with stronger tidal currents outside neap tide periods. Enhanced water movement during these months likely promotes crab activity and displacement, increasing encounter rates with fishing gear and resulting in higher catches. These months also coincide with periods when tidal flow is generally more favorable for municipal fishing operations.

A pronounced reduction in sample size was observed in September (306), the lowest among all months, which strongly aligns with the occurrence of pronounced neap tides during this period. The reduced water current during neap tides likely constrained crab movement and lowered catchability, leading to fewer individuals being captured and sampled. This pattern supports the understanding that tidal strength plays a critical role in influencing fishing success for BSC, particularly in shallow and nearshore fishing grounds.

Following September, a substantial increase in sample size was recorded in October (531), indicating a rebound in catch as tidal conditions returned to stronger current regimes. The elevated sample size in October suggests increased crab activity and improved gear performance once neap tide effects subsided. Sample sizes remained relatively high in November (453), further indicating stable fishing conditions and enhanced catchability.

Table 1: Sample size distribution and mean carapace width of *P. pelagicus*

	Mean Carapace Width (mm)									
	Feb	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**
n	373	376	364	438	419	448	423	306	531	453
Mean CW (mm)	100.9	102.2	102.7	100.7	101.9	100.6	102.7	101.6	102.9	103
SD (mm)	13.43	11.86	12.48	12.95	13.19	14.3	13	13.35	12.33	12.25

The descriptive statistics showed that crabs from Site T exhibited the largest mean carapace width (M = 103.2 mm, SD = 13.45), followed by Site Z (M = 101.9 mm, SD = 12.36), while Site M had the smallest mean carapace width (M = 100.8 mm, SD = 12.89).

Results of the one-way analysis of variance (ANOVA) revealed a statistically significant difference in mean carapace width among the three sites, $F(2, 4128) = 11.44$, $p < 0.001$. This finding indicates that carapace width, a key indicator of growth and population structure, varies significantly across locations, suggesting spatial heterogeneity in crab populations within the study area. Post hoc comparisons using Tukey's Honestly Significant Difference (HSD) test further clarified the nature of these differences. The results indicated that the mean carapace width at Site T was significantly greater than that at Site M ($p < 0.001$) and Site Z ($p = 0.029$). However, the difference between Site M and Site Z was not statistically significant ($p = 0.068$). These findings suggest that Site T may provide more favorable conditions for growth, such as higher food availability, better habitat quality, or reduced fishing pressure, compared with the other two sites.

The monthly class size distribution in terms of carapace width (CW) of *P. pelagicus* from February to November 2023 revealed notable temporal variation in population structure across the study sites in Samar. In February, smaller size classes (61–70 mm CW) accounted for only 0.80% of the sampled population, while the adjacent 71–80 mm CW class also comprised 0.80%. A marked increase in the representation of juvenile size classes was observed in March, when the 71–80 mm CW class reached 1.33%, representing an increase of approximately 66.00% relative to the previous month.

Across the sampling period, the proportional contribution of juvenile classes remained low (<1.50%) but highly variable, with coefficients of variation exceeding 40–50% across months, indicating substantial temporal fluctuation in the occurrence of newly recruited individuals. Furthermore, the 61–70 mm CW class was absent in at least two sampling months (May and August), while appearing at low frequencies in others. This pattern of sporadic presence–absence combined with irregular proportional increases suggests that entry of new individuals into the fishable population does not occur continuously at a constant rate. Instead, the data indicate episodic pulses of smaller individuals, which is consistent with intermittent recruitment events commonly observed in tropical crustacean populations where spawning and settlement occur in multiple peaks throughout the year.

However, it should also be noted that the low representation and occasional absence of smaller size classes may partly reflect gear selectivity, as fishing gears used in crab fisheries often capture larger individuals more efficiently. Consequently, the observed temporal variability in juvenile size classes likely reflects a combination of true recruitment pulses and sampling selectivity effects, both of which influence the apparent recruitment pattern in length-frequency data.

The intermediate size classes (81–90 mm and 91–100 mm CW) dominated a substantial portion of the population, ranging from 9.22% to 38.19% across months. The consistent presence of the 91–100 mm CW class, peaking in June (38.19%), is indicative of a strong sub-adult cohort contributing to the fishery. Larger classes (101–110 mm CW) also maintained high proportions throughout the study (26.25–34.22%), suggesting regular survival of individuals to near-mature sizes. Representation in the 111–120 mm CW class ranged from 14.18% to 21.09%, while the largest classes (>120 mm CW) were relatively scarce, collectively comprising less than 10% in any given month.

The relatively low representation of crabs above 120 mm CW is consistent with patterns reported in heavily exploited fisheries where larger individuals are selectively removed. In Southeast Sulawesi, Indonesia, the majority of crabs sampled had carapace widths (CW) between 40 and 100 mm, with larger individuals (≥100 mm) being scarce (Sara et al., 2017). The Jakarta Bay population showed signs of overexploitation, with an average size at first maturity of 106.81 mm CW (Panggabean et al., 2018). In East Lampung, Indonesia, heavy fishing pressure has led to faster removal of legal-sized crabs, reduced longevity, and changes in maturity patterns (Wardiatno et al., 2015). Similarly, the Kung Krabaen Bay in the Gulf of Thailand experienced a reduced mean size of mature females, from 81 mm to 75.2 mm CW, alongside elevated fishing mortality and a high exploitation rate (E = 0.71), which signaled critical stock depletion (Kunsook et al., 2014). The observed scarcity of larger size classes indicates a truncated size distribution, which is a key indicator of significant fishing pressure, with critical ecological consequences, as larger females contribute relatively more to reproductive output due to higher fecundity (Kunsook et al., 2014; Haputhantri et al., 2022).

The data from the three fishing grounds in Samar show the dominance of smaller size classes and scarcity of larger crabs, indicates similar pressure dynamics, which is a pattern well-documented as symptomatic of overharvested stocks. These patterns support the need for management measures like size-based regulations or selective gear policies.

Growth parameter estimates of *P. pelagicus*

The von Bertalanffy Growth Function (VBGF) was applied to analyze the carapace growth of *Portunus pelagicus*, a widely accepted model in fisheries biology for describing growth patterns in crustaceans. The model characterizes growth as rapid during early life stages followed by a gradual approach to an asymptotic size, making it appropriate for species with indeterminate growth such as the BSC. Growth parameters were estimated using the Electronic Length Frequency Analysis (ELEFAN I) routine in FISAT II based on monthly length-frequency data. The analysis produced a growth coefficient of K = 0.92 yr^{-1} (95% CI: 0.86–0.98 yr^{-1}) and the estimated asymptotic carapace width of $CW\infty \approx$ 148.05 mm (95% CI: 142–154 mm), indicating relatively rapid growth (Figure 2). Model fitting was evaluated using the ELEFAN goodness-of-fit index (Rn), which assesses how well the growth curve passes through the modal peaks of the length-frequency distribution. The optimized growth curve achieved an Rn value of 0.31 provided a usable fit to the observed cohort structure. These statistics suggest that the parameter estimates are relatively robust despite the inherent variability in length-frequency data.

The parameter k is associated with the growth coefficient in the Von Bertalanffy growth function, which is expressed as:

$$L_t = L_\infty\left(1 - e^{-k(t-t_0)}\right)$$

Where:

L_t is the length at age t,
L_∞ is the asymptotic length,
k is the growth coefficient,
t is the age of the organism,
t_0 is the theoretical age at zero length.

The growth coefficient (k) of *Portunus pelagicus* exhibits notable geographical variation, with comparable values reported in southwest India (0.99 yr^{-1} for males, 0.82 yr^{-1} for females; (Sukumaran & Neelakantan, 1997) and Lasongko Bay, Indonesia (0.93 yr^{-1} for males, 0.68 yr^{-1} for females; (Hamid & Wardiatno, 2015). Higher K values were observed in Oman coastal waters, with 1.85 yr^{-1} for males and 1.68 yr^{-1} for females (Mehanna et al., 2013), while a study in Jepara, Indonesia, reported a lower growth coefficient of 0.6 yr^{-1} (Hidayah et al., 2019).

The estimated growth coefficient (K = 0.92 yr^{-1}) derived from the von Bertalanffy Growth Function indicates that *P. pelagicus* in Samar can reach commercially exploitable size within approximately one year. This finding aligns with studies in similar tropical environments where *P. pelagicus* is characterized as a fast-growing species with high turnover rates. A study reported values ranging from 0.70 to 1.30 yr^{-1}, supporting the observation that these crabs typically reach maturity and marketable size within their first year of life (Abrenica et al. 2021). In fisheries biology, relatively high k values generally reflect rapid somatic growth, which may occur in populations experiencing elevated mortality rates where individuals grow quickly to reproductive or harvestable size (Pauly, 1984). While rapid growth may sustain short-term harvest yields, premature harvesting can reduce reproductive output, particularly when individuals are captured before completing multiple spawning cycles.

Evidence from other regional fisheries supports the potential consequences of sustained fishing pressure on BSC populations. For instance, a stock assessment conducted by Kunsook and colleagues (2014) in Kung Krabaen Bay in the Gulf of Thailand reported clear indicators of population stress in *P. pelagicus.* Their study documented a fishing mortality of 4.14 yr^{-1} and an exploitation rate of 0.71, substantially exceeding the estimated optimal exploitation rate of 0.38 to 0.50. In addition, they observed a decline in the average size of mature females, from 8.10 ± 0.39 cm to 7.52 ± 1.14 cm carapace width, indicating that intensive harvesting was associated with reduced size at maturity and potential truncation of the population structure.

Although the estimated growth coefficient in Samar suggests that *P. pelagicus* can rapidly attain market size, early capture of individuals may similarly reduce their reproductive contribution, increasing the risk of recruitment fishing pressure. This occurs when the spawning biomass is reduced to a level insufficient to maintain adequate recruitment into the population. Consequently, the relatively high growth rate observed in the Samar population may reflect adaptive responses to elevated mortality pressure, potentially resulting in earlier maturation and accelerated growth. Taken together, these patterns suggest that the BSC stock in Samar may be experiencing substantial fishing pressure, emphasizing the need for management strategies such as minimum size regulations, protection of berried females, and seasonal closures to maintain reproductive capacity and long-term stock sustainability.

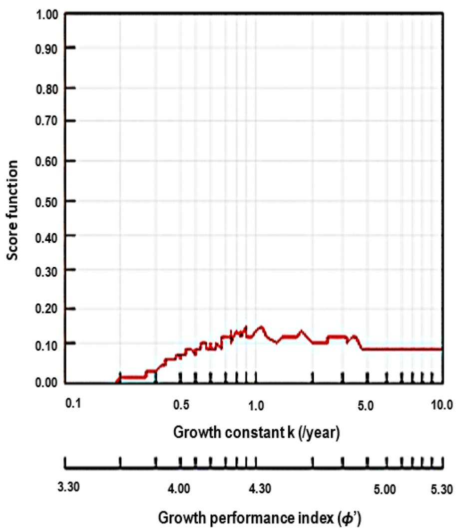

Figure 2: ELEFAN I nonparametric scoring plot for VBGF fit

Estimates of recruitment of *P. pelagicus*

The relative recruitment pattern generated from the recruitment routine in FISAT II indicates that *P. pelagicus* recruitment occurs throughout the year but with distinct seasonal peaks. The recruitment histogram (Figure 3) shows two notable peaks: the highest peak in June (16.43%) and a secondary peak in September (13.44%). These peaks represent the months with the greatest proportional entry of new individuals into the fishable stock, reconstructed from the length-frequency data using the growth parameters derived from the von Bertalanffy Growth Function.

The June peak (16.43%) suggests a major recruitment event during the early to mid-year period. In tropical crustaceans, recruitment peaks typically correspond to earlier spawning and larval settlement events, followed by several months of juvenile growth before individuals become detectable in fishery samples. The strong June recruitment pulse therefore likely reflects successful spawning that occurred several months earlier, allowing juvenile crabs to grow into the size classes captured during sampling.

A secondary recruitment peak in September (13.44%) indicates another significant increase of new individuals entering the population later in the year. The presence of two distinct peaks within a single annual cycle suggests a bimodal recruitment pattern, which is commonly reported for tropical populations of *P. pelagicus* where environmental conditions allow multiple spawning periods annually. Between these peaks, recruitment proportions remain moderate (generally below 10%), indicating that although recruitment occurs year-round, the intensity varies seasonally.

The magnitude difference between the two peaks further highlights the dominance of the mid-year recruitment pulse, with the June peak contributing the largest proportion of recruits. This pattern implies that the mid-year period may represent a critical phase for population replenishment, making it an important consideration for fisheries management. Protecting spawning females or limiting fishing effort prior to and during these recruitment peaks could help ensure sufficient recruitment to sustain the population.

This temporal pattern suggests seasonally driven recruitment fluctuations, possibly linked to environmental factors such as temperature, salinity, and plankton availability. Similar seasonal peaks have been reported in Lasongko Bay, Indonesia, where recruitment peaked in July and September, corresponding to optimal environmental conditions (Hamid & Wardiatno, 2015). Likewise, in Bancaran village, Indonesia, the highest recruitment was observed in June at 17.77% (Kamelia & Muhsoni, 2020). Along the South Karnataka coast, India, peak spawning activity was observed during February–March, with a size at maturity (50%) for females estimated at 96 mm carapace width (Dineshbabu et al., 2008). In Thailand, studies have revealed continuous recruitment patterns with peak periods varying by location, such as March to July in Ban Laem (Khowhit, 2020).

The high June recruitment in Samar, Philippines, coincides with the onset of the wet season, which may enhance larval survival by increasing nutrient input and plankton abundance. Seasonal recruitment peaks are critical for management; implementing closed seasons during these months could protect juveniles and spawning adults, a measure used in other crustacean fisheries. The variability in monthly recruitment also highlights the importance of adaptive management strategies that align fishing effort with biological cycles, minimizing fishing during peak juvenile influxes and maximizing stock replenishment potential.

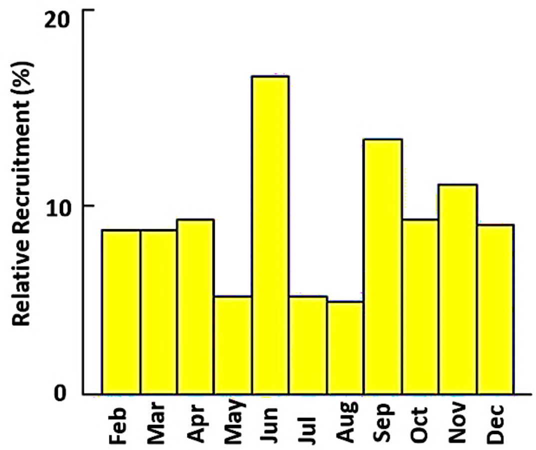

Figure 3: Relative recruitment pattern of *Portunus pelagicus* in Samar from February to November 2023

Estimates of mortality and exploitation of *P. pelagicus*

The estimates of mortality and exploitation of *Portunus pelagicus* are essential components in fisheries management, providing insights into the health and sustainability of the population. In this analysis, mortality was estimated using Pauly's M empirical equation within the FISAT II framework. The equation used for estimating natural mortality (M) is:

$$\log(M) = -0.0066 * 0.279 \log(L_\infty) + 0.6543 \log(K) + 0.4634 \log(T)$$

Where:

$L\infty$ is the asymptotic length measured in total length;
K is the VBGF growth constant; and
T is the mean annual temperature of the habitat.

The mean annual sea temperature used in the model was 28 °C, which is consistent with average coastal conditions in the fishing sites. Substituting the estimated growth parameters into the equation produced a natural mortality estimate of M = 1.08 yr^{-1}. This value represents the baseline rate of mortality due to natural causes such as predation, disease, and aging.

Total mortality (Z) was subsequently estimated using the length-converted catch curve method, which applies a linear regression to the descending limb of the catch curve derived from the length-frequency data. Only fully recruited size classes were included in the regression, while smaller, partially recruited classes were excluded to avoid bias associated with gear selectivity. In this analysis, the regression was fitted using carapace width classes within the fully recruited range of the sampled population, ensuring that the catch curve reflected true mortality patterns rather than sampling artifacts.

The regression analysis produced a total mortality estimate of Z = 2.93 yr^{-1}, with associated regression diagnostics indicating a satisfactory fit between the modeled relationship and the observed data. The coefficient of determination (R^2 = 0.8932) demonstrated a strong linear relationship between relative age and the natural logarithm of catch numbers, with confidence intervals around the estimated slope (b = −3.004; 95% CI [-6.1, 0.154]) indicated reasonable precision in the mortality estimate.

Fishing mortality (F) was estimated at F = 1.85 yr^{-1} and the exploitation rate (E) was calculated at E = 0.63, indicating that approximately 63% of total mortality in the population is attributable to fishing activities. In fisheries science, exploitation rates exceeding 0.5 are generally interpreted as indicative of high fishing pressure and potential overexploitation. The observed exploitation rate suggests that the *P. pelagicus* stock in Samar is subject to substantial harvesting pressure.

From a management perspective, such a high exploitation rate raises concerns regarding the long-term sustainability of the stock. Persistent fishing pressure at this level may reduce spawning biomass and compromise recruitment if individuals are harvested before contributing to reproduction. Consequently, the results highlight the need for appropriate management interventions, such as regulating fishing effort, enforcing minimum size limits, or implementing seasonal closures, to maintain the sustainability of the BSC fishery in Samar, Philippines.

Studies on *Portunus pelagicus* in Indonesia, Thailand, and India reveal similar concerning exploitation rates. In Indonesia's Lasongko Bay, exploitation rates were 0.61 for males and 0.71 for females, indicating overfishing (Hamid & Wardiatno, 2015). Similarly, in Toronipa waters, male crabs showed overexploitation (E > 0.5), while females remained below optimal catch levels

(Muchtar et al., 2020). In Thailand's Kung Krabaen Bay, the exploitation rate of 0.71 exceeded the optimal value of 0.38, suggesting a population in crisis (Kunsook et al., 2014). India's south Karnataka coast reported an exploitation rate of 0.65, approaching the maximum sustainable yield (Dineshbabu et al., 2008).

These results have important implications for policy implementation and fishery management. The relatively high exploitation rate underscores the need for careful management strategies to prevent overexploitation and maintain a sustainable balance in the BSC population. Potential measures include adjusting fishing quotas, implementing size limits, or establishing seasonal closures to protect vulnerable life stages during high recruitment periods, as identified in the earlier analysis.

Moreover, the estimated natural mortality (M) provides a benchmark for evaluating the sustainability of current fishing practices. If the fishing mortality (F) approaches or exceeds the natural mortality rate, it could lead to a decline in the population due to overexploitation, impacting both the ecosystem and the livelihoods of those dependent on the fishery (Mehanna et al., 2013). These estimates of natural mortality (M) and fishing mortality (F) serve as critical benchmarks for assessing fishery sustainability, particularly in *P. pelagicus* stocks. Elevated fishing mortality (F) relative to natural mortality (M) often indicates overexploitation, a pattern documented in Indonesian *P. pelagicus* fisheries where fishing mortality exceeded natural mortality by 2.5-fold, leading to recruitment impairment (Afzaal et al., 2016).

The estimates of growth, recruitment, mortality, and exploitation of *P. pelagicus* provide insight into BSC population dynamics. These findings emphasize the need for adaptive and precautionary management measures to maintain the long-term sustainability of *P. pelagicus* fisheries across the three crab fishing grounds in Samar.

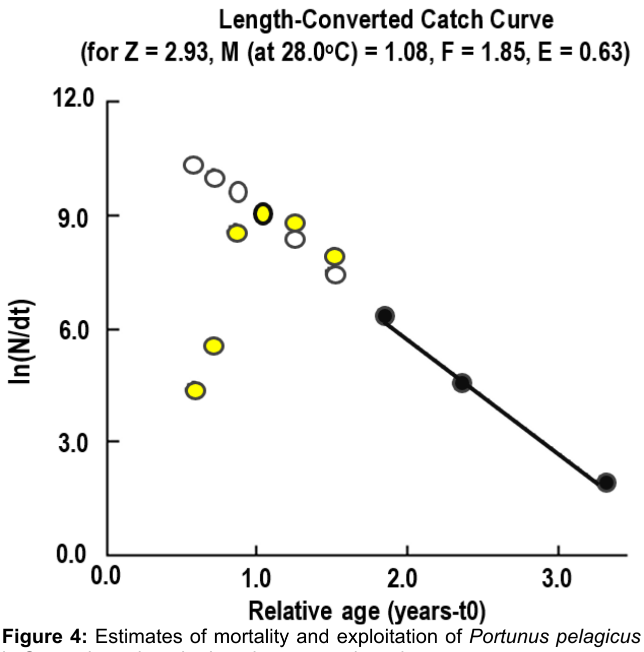

Figure 4: Estimates of mortality and exploitation of *Portunus pelagicus* in Samar based on the length-converted catch curve

CONCLUSION

This study provides an integrated view of the population dynamics of *Portunus pelagicus* in Samar, Philippines, highlighting patterns that collectively suggest increasing pressure on the stock. The observed dominance of intermediate size classes and the relatively low occurrence of large individuals point to a truncated size structure, a condition often associated with intensive harvesting and reduced spawning biomass. Together with the estimated growth coefficient (K = 0.92 yr^{-1}), the results suggest a population characterized by rapid growth but potentially limited opportunity for individuals to reach larger, highly fecund size classes.

Recruitment analysis further revealed seasonal pulses, with peaks occurring in June and September, indicating that replenishment of the population may depend on specific periods within the year when environmental conditions favor larval survival and settlement.

When considered alongside the mortality and exploitation estimates, the findings imply that fishing mortality contributes substantially to overall population loss and may exceed levels typically considered optimal for sustainable exploitation. Similar patterns have been documented in several blue swimming crab fisheries across the Indo-Pacific, where persistent fishing pressure has been linked to declining stock productivity and changes in size structure. Although the present study does not alone confirm stock collapse, the convergence of these indicators suggests that precautionary management may be warranted to maintain the long-term productivity of the resource.

In this context, management approaches that align with the biological characteristics of *P. pelagicus* could help improve stock resilience. Measures such as reinforcing minimum size limits, improving gear selectivity to reduce the capture of undersized individuals, and considering seasonal management during periods of strong recruitment may contribute to sustaining the reproductive capacity of the population. Protection of coastal nursery habitats, including seagrass beds and mangrove areas, may also support juvenile survival and long-term fishery productivity.

The study covered ten consecutive months of sampling from February to November 2023, which allowed the detection of important seasonal patterns in growth, recruitment, and size structure. However, because the dataset does not encompass a complete annual cycle, parameters described as annual should be interpreted with some caution. Extending sampling to a full year or across multiple years would strengthen future assessments by capturing additional seasonal processes and potential interannual variability. Despite this limitation, the present findings provide an important empirical basis for understanding the status of *P. pelagicus* in Samar and may serve as a useful reference for developing locally appropriate and adaptive fishery management strategies.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

CONTRIBUTIONS OF INDIVIDUAL AUTHORS

ABM was responsible for the conceptualization of the study, collection of samples, data analysis, writing or the original draft, and editing of the revision. AIBS contributed to the conceptualization, assisted in sample collection, and participated in the review and editing of the manuscript. Both authors reviewed and approved the final version of the manuscript.

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