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Blue swimming crab (*Portunus pelagicus* Linnaeus, 1758) spawner's survival and egg hatchability in net cages

Paul B. Doronila*  and Rhoda A. Aguilos 

Central Philippines State University, Ilog Campus, Washington St., Barangay 1, Ilog, Negros Occidental, Negros Island Region, Philippines 6109

*Corresponding author: pauldoronila@gmail.com

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ABSTRACT

The declining population of the blue swimming crab (BSC) (*Portunus pelagicus* Linnaeus, 1758) necessitates effective resource management and hatchery development for crablet production, which is vital for reseeded and aquaculture. This study aimed to determine the water quality and evaluate the survival rate (SR) of spawners and the hatching rate (HR) relationships to the spawners' carapace width (CW) and body weight (BW) using a net cage hatchery system in the coastal waters of Bocana, Ilog, Negros Occidental, Philippines. Berried BSC were individually stocked in net cages and grouped into five size categories based on CW: S1 (100.00-104.99 mm), S2 (105.00-109.99 mm), S3 (110.00-114.99 mm), S4 (115.00-119.99 mm), and S5 (120.00-124.99 mm). The findings indicated that the physicochemical parameters in the coastal waters of Bocana were suitable for BSC spawning. Larger CWs were associated with higher SR (mean overall $80 \pm 40.82\%$). Spawners with a CW ranging from 110 to 124.99 mm exhibited higher HRs compared to those ranging from 100 to 109.99 mm. The mean (\pm SD) hatching rate ($51.89 \pm 29.67\%$) was comparable to previous studies with highly controlled environmental conditions. The BSC spawners' CW ($r(23) = 0.614$, $P < 0.001$) and BW ($r(23) = 0.563$, $P < 0.003$) were significantly correlated with their HR. The correlation between HR vs. CW and HR vs. BW was significant. The net cage system offers a method that can contribute to a sustainable blue swimming crab fishery industry and serves as a potential model for community-based aquaculture initiatives.

Keywords: berried crabs, body weight, carapace width, fecundity, net cage hatchery system

INTRODUCTION

Worldwide, excessive fishing has resulted in a considerable proportion of marine fish populations being harvested at biologically unsustainable rates. This trend indicates a troubling escalation, with 33.1%

of evaluated fish stocks classified as overfished by 2015, a significant increase from 10% in 1974 (FAO 2018). These declines significantly affect both coastal and inland fisheries, which are frequently vital for the sustenance and economic stability of underprivileged communities (Lynch et al. 2017). The consequences of



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these declines raise serious concerns regarding global fish availability, especially in developing nations that depend heavily on marine resources. Effective management and sustainable production strategies are essential due to the ongoing demand for marine products and the significant role of fisheries in addressing poverty and ensuring food security (FAO 2018; Mesa et al. 2018).

Among these fishery resources is the blue swimming crab (BSC) (*Portunus pelagicus* Linnaeus, 1758), an economically significant species prevalent throughout the Indo-Pacific, particularly in Southeast Asia. Its high commercial value has led to increasing exploitation (Andrés et al. 2010; Baylon 2010; Qunitio et al. 2011; Azra and Ikhwanuddin 2015), which has led to a decline in natural stocks in regions like the Philippines (FAO 2018; BFAR 2018; BFAR 2020; Gascon et al. 2023). In eastern Visayas (de la Cruz et al. 2015; FAO 2018; Mesa et al. 2018; Doronila 2019) in particular, this scarcity of BSC stocks, coupled with the global understanding that reliance on finite natural resources is unsustainable, creates a strong imperative for the aquaculture of BSC. Hatchery production, particularly for commercial-scale operations, emerges as the most promising strategy for seed supply. Recent research in BSC culture has primarily focused on refining larval rearing procedures in tanks to enhance survival and growth (Azra and Ikhwanuddin 2015). However, this method is expensive to maintain in the Philippines.

To address the decline in commercial and municipal fisheries, this study examines the survival and hatching rates of blue swimming crab spawners using net cages to increase the BSC stocks for reseeding and aquaculture. Specifically, this study determined the water characteristics of the area, assessed the survival rate (SR) and the hatching rate (HR) of BSC spawners within the net cage system, and examined the relationships between the hatching rate (HR) and the spawners' carapace width (CW) and body weight (BW). The results of this study will be beneficial for the sustainability of the BSC fishery and aquaculture.

METHODS

Research Design

This study on the spawner's survival and hatching rate of blue swimming crabs in a net cage under natural conditions utilized an observation-correlational research method.

Time and Location of the Study

The research was carried out from 05 December 2020 to 27 March 2021 in the coastal waters

of Barangay Bocana, Ilog, Negros Occidental, with the coordinates 10°0'43.859"N and 122°42'29.113"E (Figure 1). It is 873 m from the shoreline, with a water depth of 80 cm during the lowest low tide and 230 cm during the highest high tide based on a zero datum mean lowest low water reference. The study site is situated in the neritic zone, a nearshore marine environment distinguished by adequate light penetration that facilitates active photosynthesis. This area generally features well-oxygenated waters, consistent temperatures, and reduced hydrostatic pressure in comparison to deeper zones, frequently composed of fine sediments like silt. The neritic zone exhibits high biological productivity, fostering a variety of communities such as phytoplankton, zooplankton, protists, small fishes, and shrimp, which collectively establish a crucial foundation for a significant segment of global fisheries (Garrison 2017; Castro and Huber 2019).

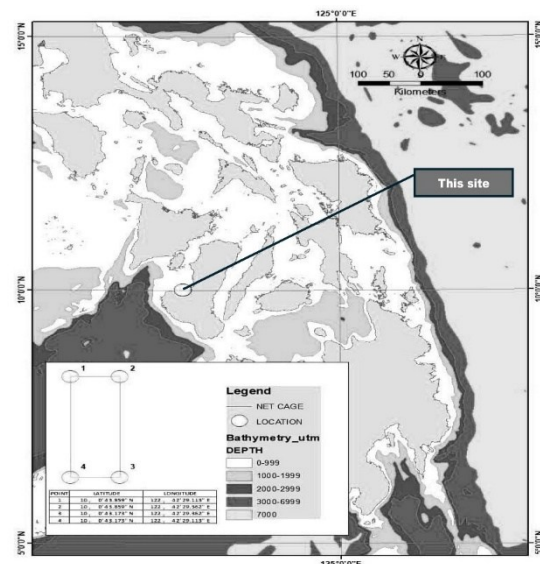


Figure 1. The study site in Barangay Bocana, Ilog, Negros Occidental, Philippines.

Field Layout

The study utilized a complete randomized design (CRD) in a floating cage area of 108 m² (Figure 2). The CRD was applied to maintain experimental rigor and ensure unbiased distribution of individuals across the different size groups (Deaton and Cartwright 2018). The floating net cage system measures 7 m in width and 21 m in length. The system contains 25 net cages designed to house the BSC spawners, each measuring 1 m by 1 m with a height of 0.5 m. Each net cage is 1 m apart to ensure adequate dissolved oxygen distribution. To examine the

relationships between spawner size and reproductive success, five distinct groups of berried BSC were established. These classifications were precisely delineated by CW, ranging from Group 1 (S1), encompassing individuals measuring 100.00 to 104.99 mm, through successive increments to Group 5 (S5), which included crabs between 120.00 and 124.99 mm. This structured grouping allowed for the rigorous assessment of how SR and HR correlate with these key morphological dimensions (Table 1). The sizes are based on the minimum legal size and the BSC female CW range at average size of maturity (Mesa et al. 2018; Abrenica et al. 2021; Gascon et al. 2023; Picoy-Gonzales et al. 2023).

Source and Collection of Spawners

The 25 stage-1 live BSC spawners were gathered within the coastal area of Barangay Bocana to ensure their viability for the study. Sourcing live, stage-1 berried spawners (Figure 3) directly from experienced local fishers ensured access to naturally gravid and healthy individuals, reflecting the typical broodstock acquisition method for local aquaculture efforts (Quinitio et al. 2011). The crabs were collected within one week to ensure minimal variances during the spawning time (Oniam et al. 2021). The collected crabs were stored in the net cages at the study site.

Preparation and Installation of Floating Net Cages

The openings of the blue High-Density Polyethylene (HDPE) plastic drum floats were first sealed using marine epoxy, then tied to bamboo frames using a plastic strap. The floats were secured to the bamboo cage frames at intervals of 7 m (Figure 4). The HDPE drums and polyvinyl chloride (PVC) pipes were chosen for their durability, buoyancy, and resilience in marine environments, to ensure the lasting integrity of the floating system (Beveridge 2004).

Each net cage was constructed using a fine-meshed nylon screen (24 mesh, 0.71 mm) sewn to dimensions of 90 cm in width and 90 cm in length, with a height of 40 cm, which is smaller than the cage frame to ensure a secure attachment. The fine-meshed nylon screen played a crucial role in containing newly hatched zoea larvae, facilitating adequate water exchange while effectively preventing predator intrusion (Cabacaba and Salamida 2015). The cage frames were made using a one-half-size blue PVC pipe, connected using the “L” and “T” connectors, and fitted with PVC solvent (Figure 5). The cages were installed three days before stocking to ensure their durability and fittings.

S2	S1	S5	S4	S1	S3	S5	S2	S5
S4	S3	S1	S2		S2	S3	S4	S3
S5	S1	S4	S3		S1	S4	S2	S5

Figure 2. Field layout of the study showing the S1 to S5, wherein S1 (100.00-104.99 mm; S2 (105.00-109.99 mm; S3 (110.00-114.99 mm; S4 (115.00-119.99 mm), and S5 (120.00-124.99 mm) are categorized as Groups 1, 2, 3, 4, and 5, respectively, and replicated 5 times in a complete randomized design within the floating cage area.

Table 1. Treatments, replications, and blue swimming crab characteristics.

Treatments (size class) (mm)	Replications/ Number of study cases	Stocking Density (m ²)	Average (±SD) Size Range Carapace Width (mm)	Average (±SD) Incubation Duration (days)
S1 100.00-104.99	5	1	101.32 ± 0.87	10.00 ± 0.00
S2 105.00-109.99	5	1	108.32 ± 0.84	10.00 ± 1.00
S3 110.00-114.99	5	1	113.18 ± 1.61	10.60 ± 0.89
S4 115.00-119.99	5	1	118.44 ± 1.25	9.50 ± 0.58
S5 120.00-124.99	5	1	123.56 ± 2.02	10.60 ± 0.55
Total	25		112.97 ± 8.00	10.20 ± 0.77



Figure 3. Stage 1 blue swimming crab spawner (*Portunus pelagicus*) used in the study, caught in the coastal area of Barangay Bocana, Ilog, Negros Occidental, Philippines.



Figure 4. The net cage system with a floating bamboo frame, where the polyvinyl chloride cage frame holds the net cage for spawning of the blue swimming crab.



Figure 5. The net cage is tied to the polyvinyl chloride pipe frame for individual blue swimming crab spawners, demonstrating the construction for isolated rearing.

Stocking of Spawners in the Net Cages

At 1800 h, when the temperature was desirable, collected live berried females (spawners) were stocked into their corresponding net cages. Stocking at this hour coincides with cooler ambient temperatures and reduced light intensity, minimizing handling stress on the crabs during transfer (Quinitio et al. 2011). The stocking distribution followed a CRD (Figure 6), with placement determined explicitly by their sizes.



Figure 6. Stocking of blue swimming crab spawners with a stocking density of one crab per 0.5 m³ net cage.

Feeding and Monitoring of the Spawners

The BSC spawners were fed daily using green mussel (*Perna viridis* Linnaeus, 1758) meat at a ration of 10% of the crab's body weight per variate after shelling and weighing (Parado-Estepa et al. 2002; Azra and Ikhwanuddin 2015). The remaining feed was frozen in preparation for the next feeding. Feeding was done once daily from 1800 to 1900 h.

The development of crab eggs was monitored daily at 0600 h. The color of each egg was visually inspected and recorded to properly detect the day of possible spawning (Ikhwanuddin et al. 2012; Soundarapandian et al. 2013).

Data Gathering

Carapace width and body weight. Before stocking the BSC spawners in their corresponding cages, the CW was measured using an electronic digital vernier caliper to the nearest hundredth from the tip-to-tip of its carapace spine. The BW of individual crabs was measured using a digital laboratory scale (SARTORIUS Practum 6101-1S). Two data points were taken for the BW: the total BW, and the BW without the eggs on its pleopods.

Water physicochemical parameters. A 200 mL bottle was submerged at approximately 50 cm deep in a bottom-up position (90°) perpendicular to the seafloor. It was then gradually tilted to 180° going upward, reaching the water column in three random points outside the individual net cages but within the study area. To ensure consistency, water samples from inside the net cages were obtained via the same

method, targeting three randomly chosen cages across all experimental groups. Water physicochemical parameters were measured using a turbidity sensor (PASCO PS-3215), an optical dissolved oxygen (DO) sensor (PASCO PS-2196), a digital temperature sensor (PASCO PS-3201), a refractometer (Magnum Media Salinity-ATC technology with Automatic Temperature Compensation) for salinity, and a wireless pH sensor (PASCO PS-3204). All physicochemical parameters were measured twice daily, from 0600 h – 0700 h when the temperature was at its minimum and from 1400 h - 1500 h when the temperature was at its maximum.

Spawners' survival rate. Crabs were monitored daily at 0600 h from day one, or the day after stocking, up to day 12 when all BSC spawned and were removed from the net cages. The survival rate of the spawners was gathered per treatment and calculated using the formula:

$$\text{Survival Rate} = \frac{\text{Number of crabs in net cage}}{\text{Live crab after spawning}} \times 100.$$

Estimation of egg mass and batch fecundity. Batch fecundity, defined as the quantity of eggs produced by a female in a single batch, and the overall egg mass attached to the pleopods during the embryonic stage were determined (Soundarapandian 2009). Embryonic stages were visually categorized by egg color (Figure 7; Ikhwanuddin et al. 2012; Soundarapandian et al. 2013): stage one (yellow or orange-yellowish), stage two (brown), and stage three (black-grey or black).

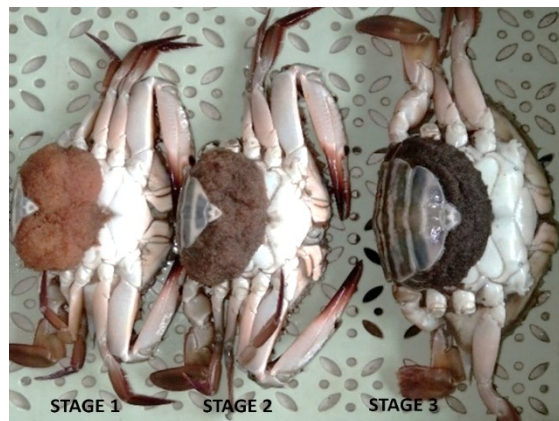


Figure 7. Egg development stages of the blue swimming crab spawners, visually categorized by color: Stage 1 (yellow or orange-yellowish), Stage 2 (brown), and Stage 3 (black-grey or black).

For the determination of fecundity from the 25 collected BSC spawners, the procedure outlined by Ikhwanuddin et al (2016) was adhered to. From each wet egg mass, three replicate subsamples were randomly collected. Eggs were then counted under an

electronic binocular light microscope (Motic®-BA210) until a count of 300 eggs was reached in each subsample. Subsequently, the mean weight of eggs per unit subsample was precisely measured using an electronic analytical balance (Sartorius BSA124S-CW Max 120 g d = 0.1 mg). Fecundity for each spawner was calculated using the following formula, adapted from Ikhwanuddin et al (2016):

$$Fecundity = \frac{Total\ egg\ mass}{Mass\ of\ individual\ egg}$$

Determination of HR per group. The spent stage occurs when the crab has released all eggs from its pleopods (Mesa et al. 2018). The spawned crab was removed from the net cage, then the net cage was removed from its PVC frame and placed in a 40 L linear low-density polyethylene (LLDPE) plastic basin. A half-filled plastic basin containing hatched larvae (zoea) was softly stirred to ensure an even distribution of zoea larvae in the water. One liter (1 L) sample was taken at random points from the plastic basin. The zoea larvae were counted using volumetric sample analysis. To quantify larval density, ten 10-mL replicate subsamples were collected from each 1 L water sample taken from the plastic basin. Larvae within each 10-mL subsample were counted, and the mean density was calculated. Subsequently, the estimated number of hatched larvae in 1 L was extrapolated to the total volume of the plastic basin to determine the total number of larvae produced. The hatching rate was then determined using the formula provided by Ikhwanuddin et al (2016):

$$Hatching\ Rate = \frac{Number\ of\ larvae\ hatch}{Fecundity} \times 100.$$

Data Analysis

All statistical analyses were performed using SPSS Statistics (IBM Corp., Version 26.0). The mean and standard deviation were used to determine the water characteristics, the spawners’ survival, and the hatching rate. Pearson’s correlation was used to

determine the relationship between the spawner's body size (CW and BW) and their HR. The assumptions of normality and homogeneity of variance were verified prior to conducting parametric analyses. A one-way Analysis of Variance (ANOVA) was conducted to evaluate significant differences across the five size groups concerning CW and BW at a 95% significance level. To mitigate Type I error in multiple comparisons, a post-hoc analysis employing Tukey’s Honest Significant Difference (HSD) test was performed to determine which specific groups exhibited statistically significant differences. The choice of these tests was carefully considered for their effectiveness in examining relationships and group differences within a normal dataset (Field 2024).

RESULTS

Coastal Water Characteristics in Bocana

The results of the water physicochemical analysis in the study area, which is located in the neritic zone of the coast of Barangay Bocana, showed the following levels: DO, 5.71 ± 0.564 mg L⁻¹; temperature, 29.18 ± 0.14°C; pH, 8.30 ± 0.12; salinity, 27.88 ± 0.39 ppt, turbidity, 130.10 ± 57.12 NTU (Table 2).

Survival Rate and HR of Blue Swimming Crab Spawners

Survival rates were highest in groups S3 and S5, both achieving 100 ± 0%. These were followed by S4 with 80 ± 44.72%. Groups S1 and S2 exhibited lower SRs at 60 ± 54.77%. The overall mean SR for BSC spawners was 80 ± 40.82%.

The HR of S1 was the lowest among the groups (26.64 ± 25.36%), while S5 had the highest among the groups (77.54 ± 1.91%). The overall HR ranged from 0.00 to 80.17% (51.89 ± 29.67%) (Table 3). Significant differences were observed between the groups, as established by one-way ANOVA (*F*(4,20)

Table 2. Water physicochemical analysis within the incubation period in the coastal waters of Barangay Bocana, Ilog, Negros Occidental, Philippines (PPT - parts per thousand, NTU - Nephelometric Turbidity Unit).

Physicochemical parameters	AM	PM	MEAN
	min, max (Mean ± SD)	min, max (Mean ± SD)	min, max (Mean ± SD)
DO (mg L ⁻¹)	4.79, 6.71 (5.42 ± 0.53)	5.21, 7.05 (6.15 ± 0.67)	4.96, 6.73 (5.71 ± 0.56)
Temperature (°C)	28.02, 29.10 (28.10 ± 0.06)	29.60, 30.67 (30.34 ± 0.30)	28.89, 29.40 (29.18 ± 0.14)
pH	8.05, 8.41 (8.31 ± 0.13)	8.05, 8.53 (8.28 ± 0.17)	8.16, 8.49 (8.30 ± 0.12)
Salinity (ppt)	26.67, 28.10 (27.82 ± 0.57)	27.50, 28.67 (28.13 ± 0.38)	27.07, 28.40 (27.88 ± 0.39)
Turbidity (NTU)	29.35, 218.83 (135.26 ± 61.04)	34.67, 209.00 (125.46 ± 54.25)	34.41, 211.20 (130.10 ± 57.12)

Table 3. Survival rate and hatching rate of blue swimming crab spawners in each 5 mm carapace width size group in the net cage in the coastal water of Barangay Bocana, Ilog, Negros Occidental, Philippines.

Treatments (size class) (mm)	Survival Rate min, max (Mean ± SD)	Hatching Rate min, max (Mean ± SD)
S1 - 100.00-104.99	0.00, 100.00 (60.00 ± 54.77)	0.00, 56.02 (26.64 ± 25.36)
S2 - 105.00-109.99	0.00, 100.00 (60.00 ± 54.77)	0.00, 55.84 (27.27 ± 25.69)
S3 - 110.00-114.99	100.00, 100.00 (100.00 ± 0.00)	60.06, 74.81 (67.83 ± 6.43)
S4 - 115.00-119.99	0.00, 100.00 (80.00 ± 44.72)	0.00, 78.09 (60.2 ± 33.92)
S5 - 120.00-124.99	100.00, 100.00 (100.00 ± 0.00)	74.85, 80.17 (77.54 ± 1.91)
Total	0.00, 100.00 (80.00 ± 40.82)	0.00, 80.17 (51.89 ± 29.67)

Table 4. Comparison of the mean hatching rate of blue swimming crab spawners based on their carapace width.

Treatments (size class) (mm)	n	Mean	Std. Deviation
S1 - 100.00-104.99	5	26.64 ^b	25.36
S2 - 105.00-109.99	5	27.27 ^b	25.69
S3 - 110.00-114.99	5	67.83 ^a	6.43
S4 - 115.00-119.99	5	60.20 ^a	33.92
S5 - 120.00-124.99	5	77.54 ^a	1.91
Total	25	51.89	29.67

Table 5. Correlations of hatching rate, carapace width and body weight of blue swimming crab spawners (**. Correlation is significant at the 0.01 level, 2-tailed)

		Hatching Rate
Hatching Rate	Pearson Correlation	1
	Sig. (2-tailed)	
	N	25
Carapace Width	Pearson Correlation	0.614**
	Sig. (2-tailed)	0.001
	N	25
Body Weight	Pearson Correlation	0.563**
	Sig. (2-tailed)	0.003
	N	25

= 5.566, $P = 0.004$). The Tukey’s HSD post-hoc test revealed that the HR’s between groups were significantly different, with S1 (26.64±25.359) and S2 (27.27 ± 25.692) showing significantly lower HRs compared to S3 (67.83 ± 6.434), S4 (60.2 ± 33.917), and S5 (77.54 ± 1.912) (Table 4). This indicates that the HRs of the larger BSC spawners with CW ranging from 110.00 mm to 124.99 mm are significantly higher than those of the smaller spawners with CWs ranging from 100.00 mm to 109.99 mm.

Correlation Between Hatching Rate and Carapace Width and Body Weight

In the current study, the HR and the CW of the BSC spawners were found to have a moderate positive correlation, $r(23) = 0.614$, $P < 0.001$. The HR and the BW were also found to have a moderate positive correlation, $r(23) = 0.563$, $P < 0.003$. These results show that the CW and BW of the BSC

spawners are significantly correlated with their HRs (Table 5). This suggests that a higher CW results in a higher HR (Figure 8), and a similar trend is observed between BW and HR (Figure 9; Figure 10).

DISCUSSION

Water Quality Conditions and Suitability

The water quality in the coastal waters of Barangay Bocana is suitable as the spawning ground for BSC. The water characteristics are considered optimum for the reproductive performance of the BSC spawners, aligning with conditions known to support crustacean reproduction, except for salinity, which is lower than that reported in previous studies (Charmantier and Charmantier-Daures 1995; Arshad et al. 2006). The optimum salinity and temperature for the hatchability of BSC are 30-32 ppt and 28-30°C,

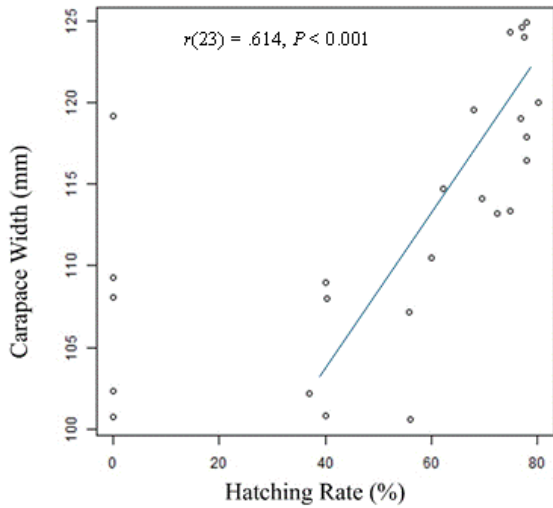


Figure 8. A scatter plot illustrates the relationship between blue swimming crab spawners' hatching rate (%) and carapace width (mm). A significant positive correlation was observed ($r(23) = 0.614$, $P < 0.001$), indicating that hatching rate tends to increase with larger carapace width. The line represents the linear regression trend.

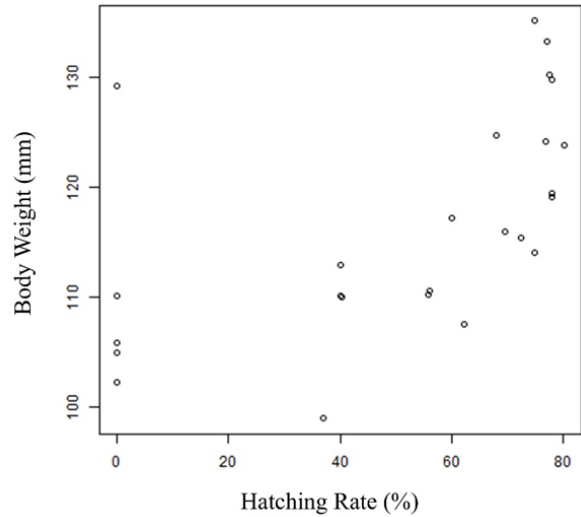


Figure 9. A scatter plot illustrates the relationship between blue swimming crab spawners' hatching rate (%) and body weight (g). A significant positive correlation was observed ($r(23) = 0.563$, $P < 0.003$), indicating that hatching rate tends to increase with larger body weight. The line represents the linear regression trend.

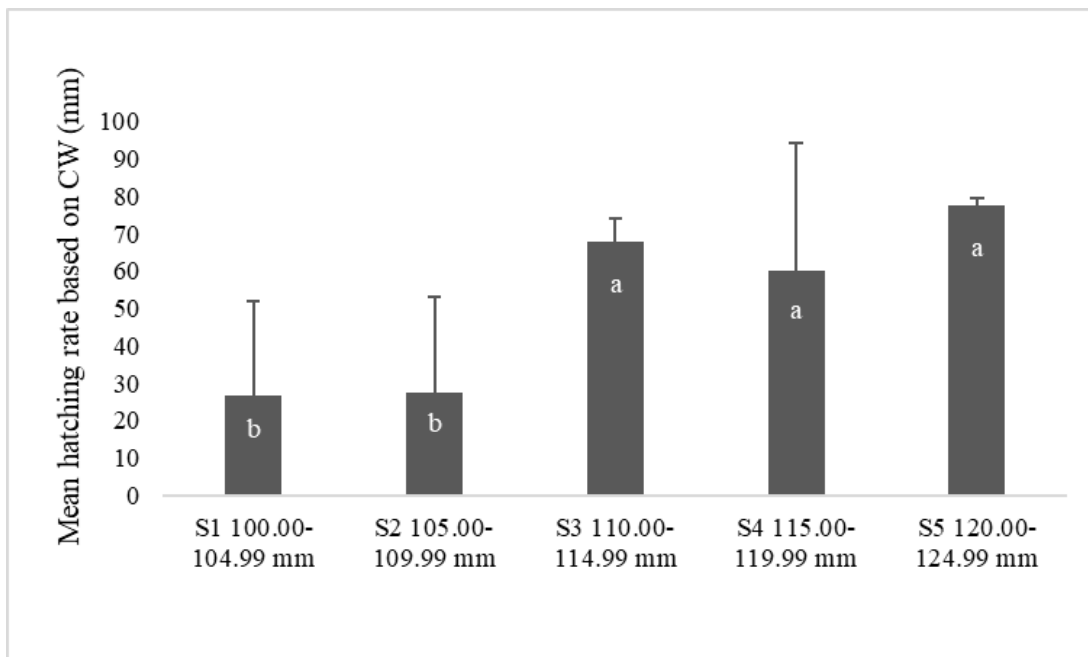


Figure 10. Comparison of the mean (\pm SD) hatching rate of blue swimming crab spawners based on their carapace width in Bocana, Ilog, Negros Occidental.

respectively (Arshad et al. 2006; Kunsook et al. 2014). Studies on the reproductive performance of BSC using a net cage in natural waters are limited. Nevertheless, it was reported that the gonad index did not significantly correlate with water transparency, dissolved oxygen, or temperature (Batooy et al. 1988). It was also noted that the reproductive cycle of the species is significantly influenced by salinity, with higher salinities being more conducive to breeding (Batooy et al. 1988). Salinity and temperature were identified as the major ecological factors affecting the distribution of the crab (Kunsook et al. 2014). Although specific studies suggest that optimal hatching occurs at 30-32 ppt (Arshad et al. 2006), the findings in Bocana showed that the best hatching percentages occurred within the 25-30 ppt salinity range. This finding may be linked to local adaptation, given that all spawners in our study were obtained from the coastal waters of Bocana, likely demonstrating physiological acclimation to the existing local conditions (Ikhwanuddin et al. 2016). A prior investigation indicated elevated spawning percentages for *P. pelagicus* in their natural environment at salinities ranging from 30 to 35 ppt, implying a general inclination for populations to adjust to their surrounding environmental conditions (Ikhwanuddin et al. 2016).

In addition, the levels of water physicochemical in the current study did not affect the reproductive performance of BSC spawners (Lignot et al. 2000; Arshad et al. 2006; Maheswarudu et al. 2008). The difficulty of seed production and water quality management in hatchery facilities in the tank needs technical expertise and state-of-the-art facilities (Cabacaba and Salamida 2015). The hatchery technique in this study, combined with a favorable coastal water site, may help simplify seed production in the country.

Influence of Spawner Size on Survival and Reproductive Output

The SR appears promising; however, the differences noted among groups necessitate additional investigations. Identifying the precise reasons for these differences necessitates a more thorough examination of the specific conditions affecting individual spawners, as the current study's framework did not facilitate a detailed analysis of mortality factors. Further extensive research is warranted to investigate the relationship between CW and SR. The encouraging SRs obtained from this innovative net cage system provide important preliminary data for the expanding field of BSC aquaculture technology and seed production. The findings indicate that the smaller size groups (S1 and S2) demonstrated lower responses

in both spawner SR and HR, especially in comparison to the larger size groups (S3, S4, and S5). The lower SRs observed in the smaller BSC spawners could be linked to physiological stress experienced during the collection and initial handling processes (Wells 2009; Oniam et al. 2021). Consequently, the reduced HR in groups S1 and S2 is directly linked to their lower SR, where a complete lack of hatching success was noted in some individuals within these groups. The variations in HRs among different size classes are probably influenced by a complex interaction of biological and environmental factors. Particularly among these are nutritional status and energy allocation toward reproduction (Litulo 2004; Leme 2006; Qunitio and Parado-Estapa 2008). Access to adequate and nutritious food is essential, as it directly influences processes like oocyte development and yolk formation. The effective distribution of energy for gonadic growth, mainly in the period leading up to the peak spawning season, plays a vital role in determining both the quantity and quality of eggs produced, which in turn affects their eventual hatchability (Soundarapandian et al. 2013). Additionally, the reproductive history of the spawners, along with the possibility of multiple spawning events during the year, could influence the variations observed in their current reproductive performance (Dickinson et al. 2006; Darnell et al. 2009; Oniam and Arkronrat 2012).

The correlation between spawner size and reproductive output identified in this study aligns with observations made in other populations of *P. pelagicus*. For example, researchers have observed that female crabs with CW ranging from 91.0 to 95.9 mm displayed the lowest levels of fecundity and reproductive potential. In contrast, the largest females (>156.0 mm CW) showed the highest fecundity and productivity (Zairion et al. 2015). They also identified the 126.0-130.9 mm CW range as containing the most fecund individuals (Zairion et al. 2015). This is consistent with the principle that larger, more mature females generally exhibit enhanced reproductive capacity (De Lestang et al. 2003; Johnson et al. 2010).

The HR recorded in this study ($51.89 \pm 29.67\%$) aligns with findings from tank-based hatchery systems reported in existing literature. An HR of $54.01 \pm 24.47\%$ has been documented for pond-reared BSC spawners that were spawned in fiber tanks (Oniam et al. 2012). Comparable findings were observed with an average HR of $56.90 \pm 22.60\%$ in a tank hatchery that employed pond-reared BSC (Oniam and Taparhudee 2010). The significance of this comparability lies in the suggestion that the net cage system, even under natural conditions with possibly less control than indoor tank facilities, can attain

comparable levels of reproductive performance. The observed hatching response is linked to reduced salinity throughout the study (Ates et al. 2011; Ikhwanuddin et al. 2016). It may also be attributed to the high turbidity of water within the site (130.10 ± 57.12 NTU) (Table 2), which is caused by the presence of non-settling suspended matters consisting of planktonic organisms and coarsely distributed non-living substances with specific gravity lower than that of water, and exceedingly finely distributed non-living materials and minute organisms such as nanoplankton (Kutty 2020). Furthermore, female BSC tend to migrate to deeper, clearer water under fair-weather conditions (Mesa et al. 2018). Turbid waters can affect species composition (Lunt and Smee 2020) and the abundance of milkfish fry (Villalva and Dolorosa 2014). Hence, to potentially enhance the reproductive performance and HR of BSC in the net cage system, there is a need to implement measures to achieve lower turbidity in the area.

Spawner Size and Reproductive Output Correlation

Although considerable research has concentrated on the reproductive performance of BSC, especially concerning fecundity or batch fecundity in relation to their morphology (CW and BW), there is a lack of literature that examines hatching performance in natural water conditions. This research gap highlights the unique contribution of the current study. In their study, Oniam and Taparhudee (2010) utilized a fiber tank with regulated water quality and discovered that CW and BW were associated solely with fecundity, rather than HR. In contrast, the current study observed moderately positive correlations between HR and both BSC spawner CW and BW (Figures 8 and 9, with $r(23) = 0.614$, $P < 0.001$ for CW and $r(23) = 0.563$, $P < 0.003$ for BW). The findings of the current study demonstrate that larger BSC spawners consistently yield a higher number of zoea larvae. This result aligns with previous studies indicating that larger BSC spawners, possessing greater CW and BW, typically produce a greater quantity of eggs compared to smaller individuals (De Lestang et al. 2003; Kumar et al. 2003; Arshad et al. 2006; Hamasaki et al. 2006; Johnson et al. 2010; Oniam et al. 2012; Soundarapandian et al. 2013; Zairion et al. 2015).

An overall spawner survival rate of $80 \pm 40.82\%$ was recorded. The results demonstrate a distinct correlation between the size of spawners and their reproductive success: larger BSC spawners, especially those with CWs between 110 and 124.99 mm, consistently exhibited significantly higher HRs than their smaller counterparts (100 to 109.99 mm).

The mean HR of $51.89 \pm 29.67\%$ achieved in this system is comparable to results from tank-based hatchery operations, which typically demand high technical skills and specialized infrastructure. Moreover, the linear and statistically significant correlations observed between the spawners' CW and BW and their HRs highlight that larger BSC spawners reliably produce higher hatching responses. The findings underscore the net cage system as a viable and practical method for improving BSC seed production.

Though this study provides valuable insights, it is important to acknowledge certain limitations. The sample size of $n=5$ per group is small, which may affect the statistical power of the ANOVA results. Although a robust post-hoc test (Tukey's HSD) was used to mitigate this, future studies should consider using a larger sample size to confirm these findings with greater statistical confidence. Furthermore, the study was conducted in a single location with specific water quality parameters, which may limit the generalizability of the results to other coastal areas. Future research should focus on replicating this study in different coastal areas and under varying environmental conditions to validate the effectiveness of the net cage hatchery system in diverse settings.

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GENERATIVE AI STATEMENT

The authors declare that NO generative AI technologies, such as Large Language Models, were used during the writing or editing of this manuscript.

ETHICAL CONSIDERATIONS

The experiment was conducted in strict compliance with national laws and institutional guidelines for animal care and use. The study protocol was reviewed and approved by the Central Philippines State University Research Ethics Review Committee.

DECLARATION OF COMPETING INTEREST

The authors assert that they have no identifiable competing financial interests or personal

affiliations that may have obstructed the work presented in this study.

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