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SHORT COMMUNICATION

Shell Dimension-Weight Relationship and Condition Index of the Invasive Mussel *Mytella strigata* in Sasmuan, Pampanga, Philippines

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ABSTRACT

A total of 300 *Mytella strigata* were collected at three sampling points in the mussel coastal demonstration farm in Sasmuan, Pampanga, and subjected to morphometric and gravimetric measurements for the evaluation of its growth pattern and condition index. Designated sampling sites were based on the distances to the river mouth (200 m, 400 m, and 600 m) with varying water quality parameters (temperature, salinity, pH, water velocity, and chlorophyll-a). Mussels in Site 2 had significantly larger shell dimensions (SL = 2.862 cm, SW = 1.458 cm, SH = 0.926 cm), shell weight (0.640 g), and total live weight (1.150 g). Significantly higher ($p < 0.05$) soft-tissue dry weight (0.083 g), however, was obtained in Site 3, while comparable ($p > 0.05$) soft tissue weight was observed in Site 2 (0.364 g) and Site 3 (0.413 g). Nevertheless, mussels in all sites demonstrated negative allometric growth ($b < 3$). The length-weight relationship revealed a weak to moderate, positive correlation. A significantly higher ($p < 0.05$) condition index was obtained in Site 3, which could have been influenced by higher chlorophyll-a and substantially lower water velocity. As such, this signifies its potential to have a well-established population in this spatial distance (600 m) from the river mouth. Hence, regular harvest and product development is recommended as strategic options to control its proliferation.

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Invasive alien species are considered major drivers of biodiversity loss worldwide (Convention on Biological Diversity 2016). Their establishment in a certain environment may implicate long-term direct and indirect impacts such as break down of biogeographic realms, decline in the abundance of native population leading to possible extinction, alteration of trophic networks, affecting fishery catches, and adversely impacting both shellfish and mangrove crab farming (Pysek et al. 2020; Joshi 2006; Fabiosa et al. 2021; Fuertes et al. 2021). In contrast, introducing non-native species also had positive impacts, including food items and livelihood opportunities to the local communities, aquaculture, and for culture and fisheries enhancement (Fuertes et al. 2021; Guerrero 2014).

In recent years, *Mytella strigata* (primarily referred to as *M. charruana* by Rice et al. 2016; Mediodia et al. 2017; Vallejo et al. 2017; Parana et al. 2019) as identified by Fuertes et al. (2021) is one of the reported invasive species that was introduced in the Philippines (Vallejo et al. 2019). This species was first reported in Manila Bay in 2014 (Rice et al. 2016) and later found to be distributed widely in the neighboring provinces like Pangasinan, Bataan, Cavite, Bulacan, Cagayan, La Union, Ilocos Sur, Zambales, and Pampanga (Parana et al. 2019; Rice et al. 2016; Fuertes et al. 2021). In addition, the species' occurrence was also recorded in Panguil Bay, Southern Philippines (Fabiosa et al. 2021). The species' potential invasiveness is reflected in its tolerance to various environmental conditions (Mediodia et al. 2017).

Currently, most of the studies on *M. strigata* in the country mainly focused on its morphological description, distribution, and invasion of the Philippine waters. Assessment of its biological condition like morphometric relationship, growth pattern, and condition index are still limited. The length-weight relationship is essential for the assessment of growth and estimation of biomass production of species (Park and Oh 2002; Aban et al. 2017). On the other hand, studying bivalve growth generates information on the environment's quality, particularly temperature and food availability patterns, as depicted in several studies (Thebault et al. 2008; Laing 2000; Mann et al. 2013). Further, the selection of site suitability for bivalve mariculture can be potentially associated with the condition index of the present animal in the area (Sasikumar and Krishnakumar 2011). The condition index is widely used as a parameter to determine the ecological and physiological status of a particular species (Zeng and Yang 2022). Moreover, the intensity of bivalve aquaculture in an area can be predicted using the condition index as an indicator (Filgueira et al. 2013). From a commercial viewpoint, the index relates the proportion of bivalve meat relative to its shell's weight, which is crucial in assessing quality and marketability (Župan and Šarić 2014). Hence, a low condition index suggests the unsuitability of the bivalve for harvest (Ezgeta-Balić et al. 2012). This parameter is commonly associated with reproductive development and food availability (Mladineo et al. 2007; Filgueira et al. 2013). The condition index increases during gonad maturation and decreases during spawning (Duisan et al. 2021).

Sasmuan is a coastal municipality of Pampanga situated along the coastline of Manila Bay. The town is known as the home of the newly conferred Sasmuan Bangkung Malapad Critical Habitat and Ecotourism Area (SBMCHEA) (DENR Region 3 2021). Recently, the local government established a demonstration farm for green mussels *(P. viridis)* in the area that will provide an adequate supply of seeds for restocking and transplantation. However, *M. strigata* was also observed to exist in the estuarine waters of Sasmuan. As this species is categorized as invasive and known to affect shellfish farming, this study was conducted to determine the important water quality variables contributing to its proliferation in the area. Specifically, the length-weight relationship and condition index were identified as biological indicators.

Mussel samples were collected in three established sampling points in the Technology Demonstration Farm of the Bureau of Fisheries and Aquatic Resources (BFAR) Regional Field Office 3 and the Local Government Unit (LGU) of Sasmuan, Pampanga (Figure 1). The designated collection area was based on the distance of culture lines from the mouth of Pasak River, namely Site 1 (200 m), Site 2 (400 m), and Site 3 (600 m).

In-situ assessments of water quality parameters such as temperature, salinity, and pH were evaluated using portable pen-type monitoring devices

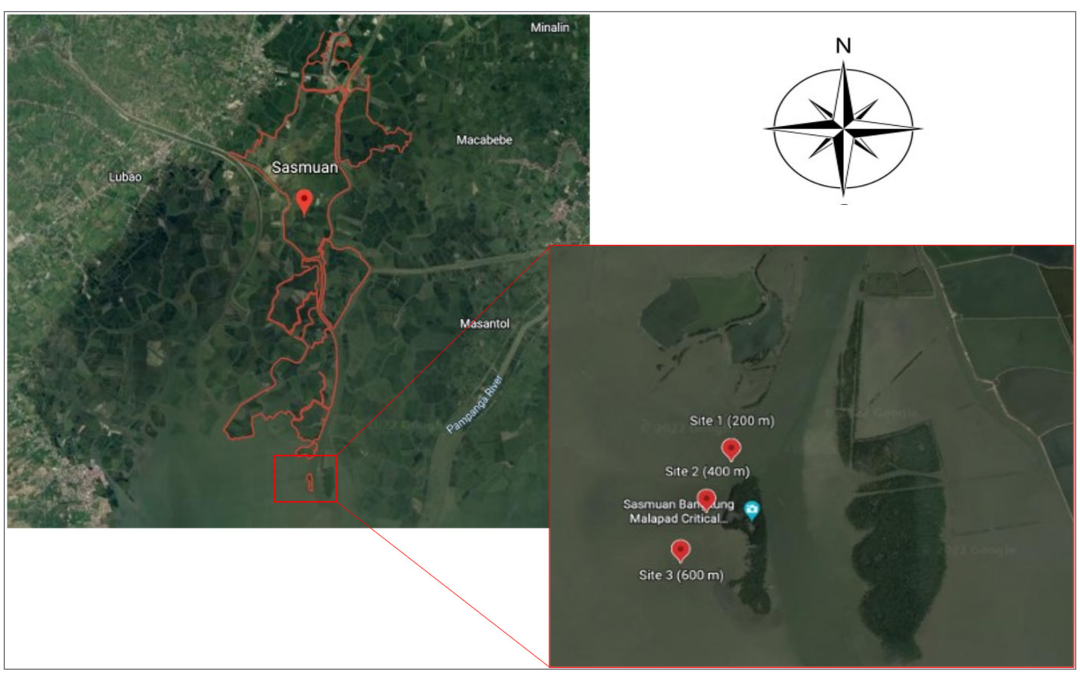

Figure 1. Map of the sampling sites (extracted from Google Earth, 2022).

(RCYAGO), while water velocity was measured with the float method. A constant volume of 100 mL of water sample was collected in the area and subjected to chlorophyll-a analysis through acetone extraction (90%) and spectrophotometric approach. The total chlorophyll-a concentration was calculated using the formula from Aminot and Rey (2001):

$$\text{Chl. a} = \frac{(11.85*(E_{664} - E_{750}) - 1.54*(E_{647} - E_{750}) - 0.08*(E_{630} - E_{750})) * Ve}{L*Vf}$$

where L is the cuvette light path (cm), Ve is the extraction volume (ml), Vf is the filtered volume (l), and Chl. a is the chlorophyll a concentration (mg m^{-3}). Each measurement of water parameters was replicated five times.

Specimens of *M. strigata* (100 per site) were randomly taken by a commissioned fisher from the culture lines. Live mussel samples were transported to the laboratory, cleaned with continuous tap water, and manually removed fouling organisms. Morphometric measurements (SL = shell length, SW = shell width, and SH = shell height) and the total live weight were taken using a digital caliper with 0.1 mm sensitivity and digital weighing balance with 0.01 g sensitivity, respectively (Figure 2). Live mussels were then subjected to freezing temperatures for 24 hours and thawed in tap water for two hours. Soft tissue was removed using a sterile scalpel. The shell and soft tissue were blotted in tissue paper and air dried for an hour. Air-dried shell and soft tissue samples were put in a preheated oven and dried at 60°C for one hour until a constant weight was obtained. Weight measurements (SDW = shell dry weight, STW = soft tissue weight) were then measured using a similar weighing balance.

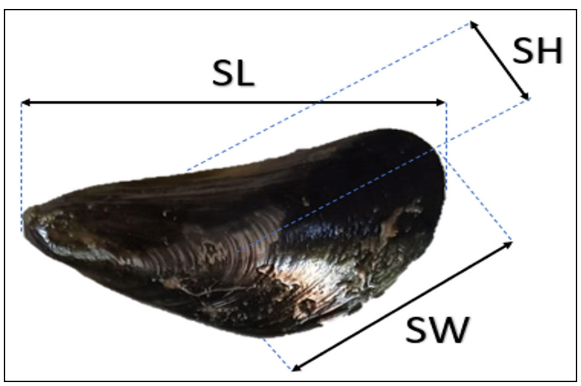

Figure 2. Illustration of dimensions in the shell of *M. strigata*.

Simple linear regression was employed to evaluate the relationships between shell dimensions (SL, SW, and SH) and total weight. Condition index was determined using the formula of Davenport and Chen (1987):
CI = (dry soft tissue weight/ dry shell weight) x 100%.

Data on the water quality parameters, shell dimensions, weight measurements, and condition index were subjected to a one-way Analysis of Variance (ANOVA). In addition, Duncan's Multiple Range Test (DMRT) was used to determine the significant differences among means of the mussel's biometric data (shell length, shell width, shell height, live weight, dry shell weight, soft tissue weight, and soft tissue dry weight) and condition index from different sampling sites.

Water quality parameters across sampling sites showed significant variations (Table 1). In the present study, temperature readings also showed significant variations based on spatial differences from the river mouth. Significant differences may associate directly with the velocity of the water (Sinokrot and Gulliver 2000). The salinity level in the coastal demonstration farm also demonstrated significant differences, where site 3 had the highest salinity concentration compared to sites 1 and 2. Nevertheless, both temperature and salinity levels across sites conform to the mean readings of Huang et al. (2021), where a higher prevalence rate (> 70%) of *M. strigata* was observed. In addition, the recorded pH levels among sites were also within the pH range of 7.51 – 8.07, as described in the study of Mediodia et al. (2017). However, significant variations in the rate of water velocity may be linked to the distances of the sites and the force of the outgoing water. This may suggest that the closer to the river mouth, the faster

Table 1. Mean readings of physico-chemical parameters in the three sampling sites.

Sampling Site	Temperature (°C)	Salinity (ppt)	pH	Water Velocity (cm s-1)	Chlorophyll-a (mg m-3)
1	28.44^{b}	21.00^{b}	7.51	19.32^{a}	0.428^{b}
2	29.42^{a}	21.14^{b}	7.52	14.58^{b}	0.699^{a}
3	29.40^{a}	21.96^{a}	7.51	10.51^{c}	0.766^{a}

Values are expressed as mean ± SD. Means in the same column having different superscripts are significantly different ($p < 0.05$).

the rate of water velocity. Further significant variations in chlorophyll-a concentration between sampling points may be associated with the water's velocity rate. Pan et al. (2009) claimed that water velocity in the lotic region affects the nutrient concentration and increases the rate of suspended solids resulting in limitation on algal growth. However, the site of the present study demonstrated a lower chlorophyll-a level, and it is below the recommended minimum concentration of 1 mg m-3 for the potential bivalve site (Saxby 2002).

There are significant variations between sites on the morphometric and weight measurements of the mussels (Table 2). The shell dimensions (SL, SW, and SH), total weight, and shell dry weight were significantly higher in site 2. The highest STW was significantly higher in sites 3 (0.413±0.239) and 2 (0.364±0.191) compared to site 1 (0.304±0.180). The soft tissue dry weight (STDW), however, was observed to be significantly higher in site 3. Existed differences may be attributed to the surrounding waters' environmental conditions among sampling sites, particularly with temperature, salinity, and chlorophyll-a. Temperature is considered a critical parameter with a pronounced effect on chemical processes (i.e., salinity) and has the strongest effect in driving plankton abundance (Boyd and Lichtkoppler 1979; Rasconi et al. 2017). These parameters were also observed among physico-chemical factors that influenced the soft tissue weight of the mussels *Perna perna* and *Mytilus galloprovincialis* (Sokolowski et al. 2010; Aziz et al. 2020). In addition, mussel specimens exhibiting significantly higher total weight congruently obtained significantly higher shell dimensions and dry weight. Findings suggest that the size of the shell corresponds to the increase in the mussel's total weight and may also be associated with the higher amount of fluid it contains (Gimin et al. 2004).

Analysis of the relationship between shell dimensions and weight in Table 3 showed that the mussels among sites grow in a negative allometric

Table 2. Morphometric and weight measurements of *M. strigata.*

Measurements	Site 1	Site 2	Site 3
SL (cm)	2.723±0.336[b]	2.862±0.343[c]	2.556±0.290[a]
SW (cm)	1.405±0.174[a]	1.458±0.174[b]	1.379±0.148[a]
SH (cm)	0.886±0.131[b]	0.926±0.132[c]	0.849±0.105[a]
TW (g)	0.872±0.282[a]	1.150±0.331[c]	1.021±0.284[b]
SDW (g)	0.539±0.173[a]	0.640±0.184[b]	0.568±0.158[a]
STW (g)	0.304±0.180[a]	0.364±0.191[b]	0.413±0.239[b]
STDW (g)	0.062±0.036[a]	0.074±0.039[a]	0.083±0.048[b]

Values are expressed as mean ± SD. Means in the same row having different superscripts are significantly different ($p < 0.05$). SL = shell length; SW = shell width; SH = shell height; TW = total weight; SDW = shell dry weight; STW = soft tissue weight; STDW = soft tissue dry weight

Table 3. Relationship of shell dimension (cm) and total weight (g) of *M. strigata.*

Relationship	n	a	b±SE	r^2	F*	Growth Pattern
Site 1 (200 m)						
SL vs TW	100	- 1.010	0.691±0.050	0.664	193.315*	(-) allometric
SW vs TW	100	- 1.129	1.424±0.082	0.754	300.723*	(-) allometric
SH vs TW	100	- 0.535	1.588±0.151	0.530	110.407*	(-) allometric
Site 2 (400 m)						
SL vs TW	100	- 0.260	0.493±0.084	0.261	34.612*	(-) allometric
SW vs TW	100	- 0.459	1.105±0.156	0.337	49.916*	(-) allometric
SH vs TW	100	0.299	0.920±0.234	0.136	15.423*	(-) allometric
Site 3 (600 m)						
SL vs TW	100	- 0.673	0.663±0.073	0.457	82.472*	(-) allometric
SW vs TW	100	- 0.636	1.201±0.151	0.392	63.079*	(-) allometric
SH vs TW	100	- 0.411	1.686±0.213	0.390	62.638*	(-) allometric

n = sample size; a = intercept; b = slope; SE = standard error; r^2 = coefficient of determination; * all *F* values are highly significant ($p < 0.01$)

pattern (b<3). Results corroborate with the findings of Barros et al. (2020), Keskin et al. (2020), Parana et al. (2019), and Aban et al. (2017) on allometry relationships in different species of mussels. Hence, "b" values obtained in the present study implied that the rate of increase in length of the mussel is faster than the rate of increase in its weight. The negative allometry could be correlated with the inadequacy of suitable food in the environment (Soon et al. 2016), which was reflected in the obtained chlorophyll-a concentration. In the wild, biometric traits of marine bivalves were positively associated with the abundance of phytoplankton (Noor et al. 2021). Other factors influencing mussel shell morphology and shell growth includes growth rate, density, salinity, temperature, and water flow (Seed 1968; Lesser et al. 2010; Telesca et al. 2018; Zajac et al. 2018). Further, the length-weight relationship revealed a weak to moderate, positive correlation. Lowest coefficient of determination (r^2) values for shell dimensions (SL, SW, SH) and live weight model is lower in Site 2 compared with Sites 1 and 3. The results in the present study had lower values than the findings of Parana et al. (2019) (r^2 = 0.811 – 0.948). Generally, about 13.6 – 75.4% of total variations in live weight can be explained by the linear model. Thus, shell dimensions are important factors that contribute to the weight of the organism, but SH has lower reliability as predictor as it has higher rate of unexplained variation in the model. Also, mussels did not gain much weight despite increasing growth in their shell dimensions. As such, it suggests that energy is invested in the growth and strengthening of shell valves for protection against adverse environmental conditions and predators (Gimin et al., 2004). Meanwhile, the result of the F-test indicates that all the slopes (b) of the regression lines significantly differ from zero.

In terms of condition index (CI), mussels from Site 3 had significantly higher CI (14.42%) than in Sites 1 and 2, with comparable mean CI of 12.20% and 11.17% ($p < 0.05$), respectively (Figure 3). Relative to the report of Parana et al. (2019), the obtained values are lower. Arrieche et al. (2020) claimed that a CI range of 2.01 to 13.49% may indicate that mussel reproduction is inactive. The better CI of mussels in site 3 could be linked to relatively higher chlorophyll-a concentration, significantly slower water velocity, and higher salinity level in the area compared with other sites. The chlorophyll-a estimates phytoplankton biomass (Flemer 1969; Pan et al. 2009). Phytoplankton serves as a primary component of the diet of filter-feeders like mussels (Hamli et al. 2020). Meanwhile, excessive current speed primarily inhibits the mussel's feeding activity, resulting in a negative influence on the CI (Noor et al. 2021). CI and salinity may associate with the clearance rate of mussel. The clearance rate is the volume of water cleared of suspended particles per unit of time (Riisgard 2001). For instance, Vlasic et al. (2018) observed that the clearance rate of the bearded horse mussel *Modiolus barbatus* increases with increasing salinity reaching a maximum of 4.23 L h^{-1} g^{-1} at 25 psu and then decreases when salinity concentration exceeds 25 psu. Further, Celik (2012) claimed that there is a variation in the CI of mussels according to the location in which environmental parameters significantly differ. The obtained CI values in the present study may also relate to the reproductive stage of the mussel. According to Hamli et al. (2017),

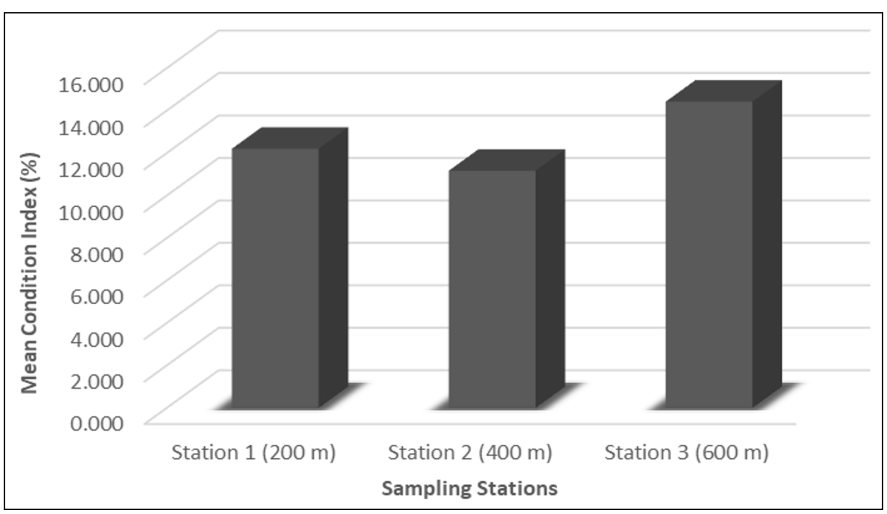

Figure 3. Mean condition index of *bahong* collected in three sampling locations in the Mussel Coastal Demonstration Farm of Sasmuan, Pampanga.

the CI increases as the gonad reaches the maturation stage, and it decreases when the gonads are at the spent and resting phase. Therefore, mussels across the sites could be characterized as an adult and are already reproductively mature based on the measured shell lengths (Stenyakina et al. 2010; Lim et al. 2018; Lodeiros et al. 2021).

This study concludes that there were significant variations in the physico-chemical conditions in the three sites. The current environmental conditions in Site 3 are favorable to support the growth of *M. strigata,* as evident by the result of morphometrics and condition index. The present findings can be used as an essential reference for developing effective monitoring and management strategies to counter the invasive nature of the species in the area and eliminate its threat against the farming of green mussels. However, a study that will emphasize the extent of its invasiveness and economic impact on green mussel farming must be investigated to identify appropriate policies to secure the viability of the existing green mussel farming in the area. Moreover, it is recommended for future studies to focus on the improved utilization of the invasive species, of which the present findings can be used as a baseline. Among the potential strategies to control its population is to use the species for developing and commercializing food and non-food products. However, studies with a broader scope that will capture spatial and temporal evaluation of the overall condition of its population in the coastal waters of Pampanga and nearby areas are indispensable to determining its viability to support such undertakings.

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AUTHOR CONTRIBUTION

Mendoza DM: Conceptualization, Methodology, Investigation, Formal Analysis, Writing - Review and Editing. **Aquino MGB:** Methodology, Formal Analysis, Writing - Review and Editing. **Mendoza GC:** Methodology, Formal Analysis, Writing - Review and Editing.

CONFLICTS OF INTERESTS

The authors declare that there is no conflict of interest in the publication of the research findings.

ETHICS STATEMENT

No animal was used or subjected by the authors to experimental studies.

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