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# Water quality in relation to the proliferation of Charru Mussel in Bacoor and Manila Bay, Philippines

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## Abstract

The Philippines' birthplace of mussel farming, Bacoor Bay, has been repeatedly threatened by *Mytella strigata*, which was first recorded in the area in 2014. Some studies addressed the relation between *M. strigata* and water parameters, but they are insufficient to predict the species' potential geographical range expansion, which is essential for anticipating their spread and establishing new populations. The relationship between anthropogenic activities and the abundance and morphology of *M. strigata* was assessed in this study, which is previously unexplored in the literature. The study was conducted in three distinct sampling sites emerged as strategic focal points, each established upon the level of anthropogenic influences. Sampling was conducted across selected months between September 2021 and August 2022 to capture the seasonal variations in the Philippines. The dominance of *M. strigata* during the Southwest Monsoon and in area with minimal anthropogenic activities emphasized its preference for specific water quality parameters and temperature conditions. Lower total dissolved solids (TDS), salinity and electrical conductivity alongside warmer water temperatures are conducive to the proliferation of *M. strigata*. Anthropogenic activities impacting the water quality index did not appear to be the primary determinant influencing the abundance and morphology of *M. strigata*. The distribution of *M. strigata* is aided by longshore currents that enhance larval dispersal during the Southwest Monsoon, proving the role of seasonal currents in the spread and colonization of this invasive species in coastal environments.

**Keywords:** Anthropogenic activities; Coastal ecosystem; Invasive species; *Mytella strigata*; Water quality.

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## 1. Introduction

The introduction of non-native species (NNS) is a major global concern, one of the biggest dangers to aquatic biodiversity and human welfare (Green and Grosholz, 2020; Iacarella *et al*., 2019; Pyšek *et al*., 2020). NNS have been purposefully and unintentionally brought into tropical waterways, whereupon some of them have established themselves, spread to other regions, and had negative ecological effects including disease, predation, competition, and habitat modification (Alidoost Salimi *et al*., 2021; Zhang *et al*., 2020). The degree of co-occurrence and interaction of NNS with other human disturbances has a significant impact on its effects, which can differ over time and geography (Gissi *et al*., 2021). One of these invasive species is *Mytella strigata* (Hanley, 1843) or *Mytella charruana* (d'Orbigny, 1842), with the common name Charru mussels. Originating from the tropical Atlantic and western Pacific coastlines of Central and South America, this species was first reported in the southeastern United States in 1986. Since then, it has proliferated extensively, establishing significant populations in Florida and Georgia (Calazans *et al*., 2017). Its range has expanded further, reaching the Caribbean coast of Venezuela (Lodeiros *et al*., 2021), indicating its ongoing spread and adaptability to various coastal environments. The first record of *M. strigata* in Southeast Asia was documented by Rice *et al*. (2016) in the Philippines. This initial finding was soon followed by reports in several other countries, including Singapore (Lim *et al*., 2018), India (Jayachandran *et al*., 2019; Ravinesh *et al*., 2023), Taiwan (Huang *et al*., 2021), and Thailand (Wangkulangkul *et al*., 2022; Wells *et al*., 2024). Additionally, *M. strigata* has been recorded in Guangdong, Hainan, and Hong Kong in China (Joyce *et al*., 2023; Ma *et al*., 2022; Yu *et al*., 2023), illustrating its rapid and widespread dispersal across the region.

It has been hypothesized that the proliferation of *M. strigata* onto the shores of Southeast Asia was due to shipping, with the most feasible source population from the Caribbean coast of South America (Yip *et al*., 2021). The northern part of Bacoor Bay is home to Cavite City's port facilities, which include the country's main naval facility and a docking area for many foreign seagoing vessels. This positioning suggests that the introduction of this alien mussel into Philippine waters could plausibly be attributed to ship ballast water discharges (Rice *et al*., 2016). Since 2016, *M. strigata* has been observed continuously and harmed Bacoor Bay, the birthplace of mussel farming in the Philippines. The total area of cultivation farm in Bacoor bay is estimated to have at least 707 hectares and the abundance of cultivated species can support the economy and food resources of the people surrounding the area.

The dark blue to brown hue, the bluish to purplish nacreous interior, and the more angular valve form set *Mytella* apart from *Perna* and *Modiolus*. It was distinguished from *Brachidontes* by its valve's absence of radial ribs. It was also differentiated from the non-indigenous *Mytilopsis* by its larger size, *Mytilopsis* in Manila Bay having a size not exceeding 1 cm in shell length (Vallejo *et al*., 2017). *M. strigata* constitutes a significant rival for space on floating substrates. *M. strigata* covers infrastructure used in aquaculture like nets and ropes by attaching themselves and forming an impenetrable barrier for water and oxygen flow to the farmed organisms (Lim *et al*., 2018). Among mussel species, *M. strigata* and *Perna viridis* compete for recruitment space, with *M. strigata* potentially recruiting at least 30 days earlier, giving it an advantage. Consequently, residents in traditional shellfish farming areas harbor negative perceptions of these non-indigenous species as this was not regarded as a food item (Fuertes *et al*., 2021).

The literatures about *M. strigata'*s environmental conditions that could promote establishment may not be sufficient to predict their potential spread. Making decisions on management actions is hampered by uncertainties in estimating the distribution of this species and identifying the factors that define habitat invasibility, vulnerability, and resilience (Katsanevakis and Moustakas, 2018). In this study, the impact of anthropogenic pressures and various stressors on water quality and the abundance of *M. strigata* was assessed. This research aimed to understand its ability to thrive under different environmental conditions influenced by human activities. This research is essential because it helps predict the potential geographical range expansion of *M. strigata*, aides in the anticipation of their spread and establishment of new populations.

## 2. Materials and methods

### *2.1. Study area*

Three distinct sampling sites emerged as strategic focal points in the location of the study (Figure 1) where each are predicated upon the level of anthropogenic influences.

The collection of water samples was conducted in three different sampling sites in Bacoor Bay (along the coast of Barangay Sineguelasan Bacoor City, Cavite and Manila Bay. Bacoor Bay is situated in the Luzon islands, specifically in Cavite, Philippines. It is a massive inlet in the southeastern part of Manila Bay in Metro Manila, ranging from 5240ha. This bay operates as a central anchorage of the Cavite Naval Base. The Manila–Cavite Expressway, which connects the province to Metro Manila, was extended along the coast of Bacoor Bay for a total length of 7 km. Bacoor Bay has a shallow seabed level of about 1.0 m below mean lower low water with a seabed slope ranging from 1/1000 to 1/2000. One likely source of sediment deposition in Bacoor Bay is littoral drift from Manila Bay. On the other hand, Manila Bay is one of the main harbors in the Philippines. It is placed in the southwest portion of Luzon Island and is described as a semi-enclosed estuary in front of the South China Sea. The bay sits in the coordinates between 120° 28´ to 121° 15´ east Longitude, and between 14°16´ to 15° north Latitude. The length of the bay is 60 km long as it enters the Corregidor and Caballo Islands. The bay has a surface area of 1800 $km^2$ and a coastline of 190 km. Manila Bay serves as a port for both domestic and foreign ships, as well as a tourist attraction, a breeding ground, and an aquafarm for freshwater fishes, oysters, and mussels. Manila Bay is surrounded by highly urbanized and rapidly urbanizing communities. Both Bacoor and Manila Bay have many environmental issues ranging from land and sea-based pollution, sedimentation, harmful algal blooms, over-exploitation of fishery resources, etc. (Vallejo *et al*., 2017).

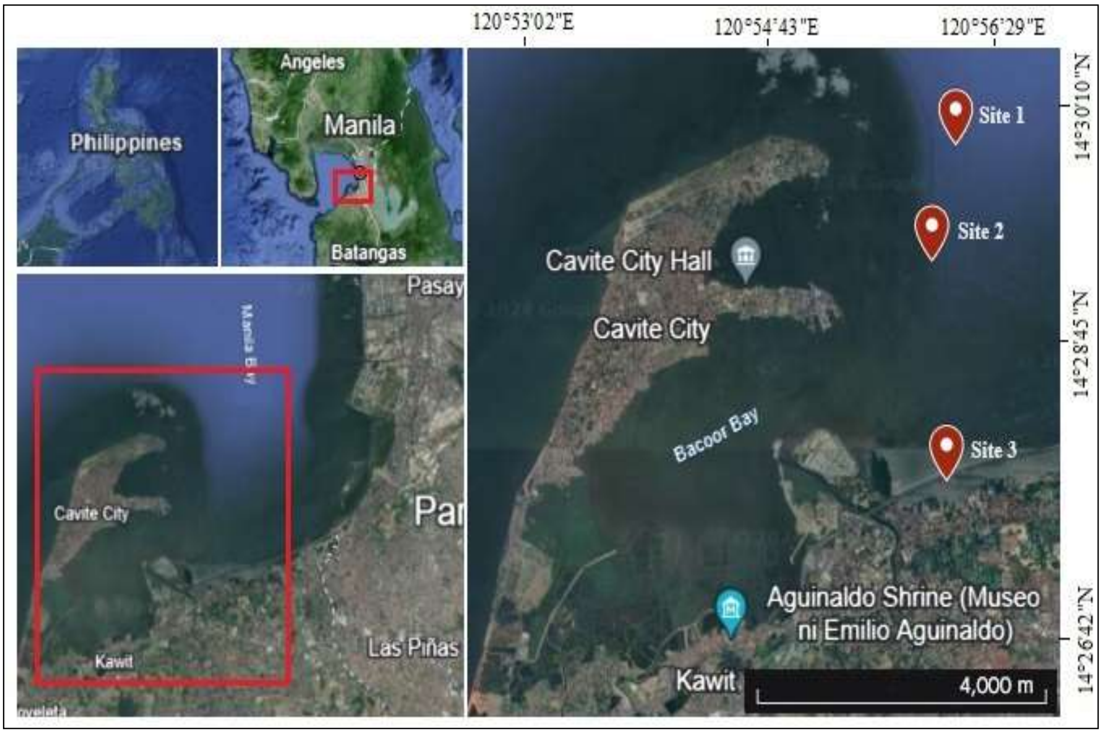


Figure 1. Location of Bacoor and Manila Bay, indicating the sampling sites of *M. strigata*

Site 1 is characterized by deep waters with minimal intervention from human activities, aside from *P. viridis* farming. This location is relatively undisturbed by anthropogenic influences, maintaining a more natural ecological balance. It has a latitude coordinate of 14° 29' 56.9" N and longitude coordinates of 120° 56' 07.8" E. Site 2 was situated in a highly cultivated area between Site 1 and Site 3 with a Latitude of 14° 29' 11.6" N and Longitude of 120° 55' 56.9" E. Site 2 is near the port facilities of Cavite City, which include the country's principal naval center and harbor for many overseas nautical vessels. The location is close to the Cavite Province municipalities of Kawit and Binakayan, which are recognized as the initial colonization sites of *M. charruana* mussels. Site 3, being close to residential areas, experiences several anthropogenic activities. These include urban runoff, sewage discharge, waste disposal, and recreational activities such as boating and fishing. Despite its proximity to Cavite City and Kawit, the site benefits from a natural landform that shields it from strong water currents originating from these urban centers. It has a Latitude coordinate of 14° 27' 45.9" N and Longitude coordinate of 120° 56' 03.6" E. Each sampling site is further segmented into three sampling points.

## 2.2. *Procedures*

### *2.2.1 Sample collection and processing*

Sampling was conducted across selected months between September 2021 and August 2022 to capture the seasonal variations in the Philippines.. Specifically, sampling events occurred during key months: September 2021, characterized by the influence of the Southwest Monsoon, also known as “habagat” which brought frequent rainfall and elevated humidity.; December 2021 and January 2022, coinciding with the Northeast Monsoon or “amihan”, marked by the arrival of a cool and dry northeast wind originating from Siberia and China, sweeping down to Southeast Asia. During this phase, slight to moderate rainfall prevailed. The sampling was also conducted in the months of April and May 2022, recognized as the peak of the Philippines' hottest and driest period, and informally referred to as "summer." The sampling concluded in August 2022, coinciding with the resurgence of the Southwest Monsoon season. Throughout these sampling events, water quality parameters such as temperature, pH, total dissolved solids (TDS), electrical conductivity (EC), and salinity were measured in situ using a 5-in-1 Water Quality Tester while dissolved oxygen (DO) was determined using JPB-70A DO Meter. Three trials at each sampling point for the three sampling sites were performed. A Secchi disk was used to measure water clarity by lowering it into the water until it disappeared, noting this depth, and then raising it until it reappeared, noting this depth as well. The average of the disappearance and reappearance depths was calculated to determine the water clarity.

For ex-situ analysis including, total coliform count, as well as phosphate and nitrate levels, water samples were collected through composite sampling at the three designated points. The samples were held in an ice chest at 20 °C and were transported immediately to a chemical laboratory for analysis. The determination of Biological Oxygen Demand (BOD) was carried out employing the 5-Day BOD Test. For the quantification of phosphate concentrations, UV–VIS Hitachi Spectrometer was used via stannous chloride method at a wavelength of 650 nm. Screening method in the ultraviolet (UV) range was deployed for nitrate quantification, with wavelengths of 220 nm and 275 nm. The total coliform count was determined by Multiple Tube Fermentation Technique.

Using the data gathered, the water quality index was calculated using the weighted Arithmetic Index Method (Brown *et al*., 1972). The water quality rating or $q_n$ was computed as shown below:

$$q_n = 100\,(v_n - v_i)/(v_s - v_i) \qquad (1)$$

where:

$n$ = water quality parameters

$q_n$ = water quality rating corresponding to an nth parameter

$v_s$ = standard value

$v_n$ = observed value and

$v_i$ = ideal value.

Water quality rating or $q_n$ is a number reflecting the relative value of this parameter in the polluted water with respect to its standard permissible value. In most cases, $v_i = 0$ except in certain parameters like pH and dissolved oxygen. For these two, equation 2 is followed:

$q_{pH} = 100 (v_n - 7.0) / (vs-7.0)$ and $q_{DO} = 100 (v_n - 14.6) / (v_s -14.6)$ (2)

The Unit Weight ($w_n$) was computed using the equation 3.

$wn = K/S_n$ (3)

where:

$w_n$ = unit weight for nth parameter

$S_n$ = Standard permissible value for nth parameter

k = proportionality constant ($K= 1/\Sigma(1/S_i)$)

The WQI is then calculated by the following equation:

$$\mathrm{WQI} = \sum_{n=1}^{n} q_n w_n \,/\, \sum_{i=0}^{n} w_n \quad (4)$$

The index was then interpreted according to the following scale: 0–25 (excellent), 26–50 (good), 51–75 (bad), 76–100 (very bad), and above 100 (unfit). Mean values were compared with the water quality standards for class SB-Marine waters based on the Department of Environment and Natural Resources Administrative Order (DAO) No. 34 Series 1990, DAO 2016–08 and DAO 2021–19.

### *2.2.2 Cultivation of M. strigata*

The collection of *M. strigata* was accomplished using the longline method, a widely employed approach in the Philippines for mussel farming. Cultivation was initiated one month prior to each sampling event. Longline method involved affixing two empty gallon bottles to opposite sides of a sturdy rope, serving as buoy markers. The rope, measuring between 5m to 8m in length and with a thickness of approximately 9.5mm, featured an attachment of three nets spanning 3m to 8m each. A massive rock was positioned beneath the rope, facilitating its settlement at the water's bottom. During the harvest phase, the byssal thread was cut, while leaving the mussel's body intact for proper collection. The collected *M. strigata* samples were counted, and their morphology, including length and width, was measured using a vernier caliper. Additionally, their mass was determined using a digital weighing scale.

## *2.3. Data analysis*

Environmental data are presented as means with standard deviations (SD) following descriptive analysis. Pearson's product-moment correlation was used to analyze the relationship between the abundance and morphology of *M. strigata* and various water quality parameters, with significance levels set at 0.01 and 0.05. Additionally, it was applied to examine the correlation between the water quality index and the abundance and morphology of *M. strigata*. Additionally, canonical correspondence analysis was conducted to further explore the *M. strigata* -environment relationships. The Social Package for Social Science (SPSS) and the PAST (Paleontological Statistics) software were utilized to analyze the collected data.

## 3. Results and Discussion

### *3.1. Water Quality of Bacoor and Manila Bay*

Table 1 displays the physico-chemical characteristics of water in Bacoor and Manila Bay across different seasons, while Table 2 presents the statistical analyses assessing variations in these parameters across sampling periods.

Table 1. Seasonal variations of water in Bacoor and Manila Bay from September 2021–August 2022

| Water Parameters | Sites | Habagat (Southwest) | Amihan (Northeast) | | Summer (Intermonsoon) | | Habagat (Southwest) |
|---|---|---|---|---|---|---|---|
| | | Sept 2021 | Dec 2021 | Jan 2022 | Apr 2022 | May 2022 | Aug2022 |
| Temperature (℃) | Site 1 | 30.30 (±0.38) | 27.33 (±0.39) | 27.23 (±0.28) | 28.03 (±0.32) | 28.29 (±0.33) | 28.68 (±0.21) |
| | Site 2 | 30.92 (±0.80) | 27.14 (±0.27) | 27.29 (±0.37) | 27.72 (±0.68) | 28.70 (±0.25) | 29.06 (±0.45) |
| | Site 3 | 33.23 (±0.52) | 28.51 (±0.33) | 27.63 (±0.22) | 28.80 (±0.40) | 28.56 (±0.75) | 28.92 (±0.51) |
| Clarity (cm) | Site 1 | 537 (±36) | 340 (±39) | 169 (±14) | 467 (±14) | 615 (±58) | 334 (±5.51) |
| | Site 2 | 307 (±5) | 230 (±9) | 117 (±12) | 308 (±1) | 180 (±25) | 303 (±4.16) |
| | Site 3 | 71 (±15.10) | 72 (±10) | 72 (±1) | 99 (±7) | 76.33 (±2) | 132 (±11.51) |
| Salinity (ppt) | Site 1 | 28.86 (±0.16) | 32.30 (±0.25) | 31.10 (±0.80) | 31.81 (±0.78) | 32.69 (±0.13) | 23.12 (±0.25) |
| | Site 2 | 27.28 (±0.41) | 31.02 (±0.19) | 31.72 (±0.23) | 31.76 (±0.43) | 31.56 (±0.21) | 22.09 (±0.20) |
| | Site 3 | 27.13 (±0.30) | 31.6 (±0.35) | 30.81 (±0.17) | 30.03 (±0.18) | 32.13 (±0.44) | 22.63 (±0.53) |
| TDS (ppt) | Site 1 | 33.01 (±0.13) | 36.87 (±0.26) | 36.11 (±0.28) | 36.61 (±0.24) | 37.25 (±0.13) | 27.14 (±0.18) |
| | Site 2 | 31.31 (±0.54) | 35.49 (±0.23) | 35.96 (±0.18) | 36.41 (±0.50) | 36.34 (±0.60) | 26.02 (±0.21) |
| | Site 3 | 31.15 (±0.33) | 36.17 (±0.34) | 35.26 (±0.28) | 34.32 (±0.22) | 36.63 (±0.46) | 26.77 (±0.57) |
| EC (mS/cm) | Site 1 | 47.16 (±0.18) | 52.65 (±0.35) | 51.59 (±0.40) | 52.30 (±0.34) | 53.22 (±0.28) | 38.77 (±0.25) |
| | Site 2 | 44.73 (±0.77) | 50.70 (±0.33) | 51.61 (±0.37) | 51.98 (±0.69) | 51.60 (±0.33) | 37.18 (±0.29) |
| | Site 3 | 44.50 (±0.47) | 51.67(±0.48) | 50.38 (±0.33) | 49.03 (±0.31) | 52.33 (±0.66) | 38.25 (±0.82) |
| pH | Site 1 | 7.74 (±0.03) | 7.10 (±0.04) | 7.51 (±0.11) | 7.34 (±0.04) | 7.22 (±0.06) | 7.05 (±0.02) |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Site 2 | 7.58 (±0.04) | 7.14 (±0.02) | 7.15 (±0.05) | 7.17 (0.03) | 7.16 (±0.03) | 7.02 (±0.03) |
| | Site 3 | 7.68 (±0.03) | 7.20 (±0.04) | 7.10 (±0.02) | 7.04 (±0.03) | 7.21 (±0.04) | 6.88 (±0.04) |
| DO (ppm) | Site 1 | 6.46 (±0.25) | 5.69 (±0.26) | 4.09 (±0.21) | 5.77 (±0.12) | 5.63 (±0.20) | 6.17 (±0.30) |
| | Site 2 | 4.80 (±0.11) | 6.83 (±0.12) | 5.08 (±0.17) | 5.63 (±0.11) | 6.26 (±0.17) | 6.08 (±0.10) |
| | Site 3 | 4.54 (±0.57) | 5.26 (±0.64) | 4.60 (±0.22) | 4.67 (±0.07) | 5.04 (±0.35) | 4.67 (±0.19) |
| BOD (ppm) | Site 1 | 3.00 (±1.00) | 3.00 (±0.00) | 2.00 (±0.50) | 3.00 (±0.50) | 4.00 (±1.00) | 2.00 (±0.00) |
| | Site 2 | 4.00 (±1.00) | 3.00 (±0.00) | 5.00 (±1.00) | 3.00 (±0.00) | 4.00 (±1.00) | 2.00 (±0.50) |
| | Site 3 | 6.00 (±2.00) | 6.00 (±1.00) | 6.00 (±1.00) | 5.00 (±0.50) | 7.00 (±1.00) | 5.00 (±1.00) |
| Phosphates (ppm) | Site 1 | 0.011 (±0.01) | 0.010(±0.00) | 0.008 (±0.00) | 0.007 (±0.00) | 0.010 (±0.00) | 0.163 (±0.00) |
| | Site 2 | 0.020 (±0.01) | 0.049 (±0.01) | 0.063 (±0.01) | 0.026 (±0.01) | 0.020 (±0.01) | 0.166 (±0.01) |
| | Site 3 | 0.265 (±0.04) | 0.245 (±0.04) | 0.487 (±0.01) | 0.338 (±0.03) | 0.051 (±0.01) | 0.209 (±0.00) |
| Nitrates (ppm) | Site 1 | 1.51 (±0.45) | 2.54 (±0.16) | 1.20 (±0.10) | 1.83 (±0.03) | 1.58 (±0.02) | 0.943 (±0.01) |
| | Site 2 | 2.02 (±0.17) | 1.87 (±0.14) | 2.60 (±0.21) | 2.08 (±0.12) | 1.63 (±0.07) | 2.88 (±0.11) |
| | Site 3 | 1.72 (±0.18) | 3.11 (±0.22) | 1.38 (±0.16) | 2.22 (±0.13) | 2.45 (±0.16) | 0.995 (±0.03) |
| Total coliform MPN 100 m/L | Site 1 | 540 (±10) | 240 (±40) | 240 (±20) | 700 (±10) | 5400 (±50) | 79 (±7) |
| | Site 2 | 5400 (±500) | 240 (±30) | 33 (±5) | 540 (±20) | 33 (±4) | 270 (±30) |
| | Site 3 | 5400 (±600) | 2400 (±400) | 130 (±15) | 9200 (±100) | 9200 (±110) | 3300 (±180) |

Table 2. Friedman's two-way ANOVA test analysis: comparing the water quality across different seasons (per site)

| Water Parameters | Site 1 | | Site 2 | | Site 3 | |
|---|---|---|---|---|---|---|
| | p–value | Remarks | p–value | Remarks | p–value | Remarks |
| Temperature | .000 | Significant | .000 | Significant | .000 | Significant |
| Clarity | .006 | Significant | .009 | Significant | .069 | Not Significant |
| TDS | .000 | Significant | .000 | Significant | .000 | Significant |
| Salinity | .000 | Significant | .000 | Significant | .000 | Significant |
| Conductivity | .000 | Significant | .000 | Significant | .000 | Significant |
| pH | .946 | Not Significant | .598 | Not Significant | 1.00 | Not Significant |
| DO | .000 | Significant | .066 | Not Significant | .273 | Not Significant |
| BOD | .259 | Not Significant | .011 | Significant | .727 | Not Significant |
| Nitrates | .607 | Not Significant | .223 | Not Significant | .115 | Not Significant |
| Phosphates | .030 | Significant | .115 | Not Significant | .513 | Not Significant |
| Total Coliform | .011 | Significant | .003 | Significant | .030 | Significant |

Anthropogenic influences on aquatic ecosystems, such as heated discharges and global climate change, significantly disrupt these environments, often resulting in increased water temperatures. This rise in temperature not only favors invasive species by creating more suitable conditions but also diminishes the competitive edge of native species, leading to shifts in species distribution and abundance, as documented by Finch *et al.* (2021).The situation is particularly alarming in Bacoor and Manila Bay, where the classification of the marine water as class SB indicates a need for stringent environmental management. Based on Table 1, the minimum temperature measured is 27.14 °C and the maximum is 33.23 °C. The elevated temperature emphasizes the urgent need to address human-induced temperature increases in the bay, especially with Site 3 due to high secchi disc turbidity, heated discharges from land reclamation activities, illegal squatting along the coastline and industrial wastewater discharges. These stressors are interconnected, driven by the city's pursuit of economic growth and urbanization. The drive for development has led to an increase in these detrimental activities, significantly impacting the coastal waters in Bacoor Bay and Manila Bay, specifically site 3. Coastal ecosystems suffer substantial transformations to the point where they lose their integrity due to the rapid development of coastal urbanization, which also has a dramatic impact on other environmental components (Sahavacharin *et al*., 2022).

The data highlights significant differences in water clarity among the three sites. Clarity measurements revealed the following ranges: Site 1 ranged from 169 cm to 615 cm, Site 2 ranged from 117 cm to 308 cm, and Site 3 ranged from 71 cm to 132 cm. The variations could be attributed to local factors such as sediment load, human activities, and hydrological dynamics. The lower clarity values at Site 2 and Site 3 suggest a higher presence of suspended particles and turbidity. Elevated turbidity can be caused by sediment runoff, pollution, and other anthropogenic influences (Scott and Haggard, 2021). Based on

Friedman test, seasonal changes in air temperatures and the influence of cool, dry North-East winds, also known as Amihan, contribute to the recorded temperature variations, as indicated by the significant difference in temperature ($p < 0.05$). Except for Site 3, there is significant variation in water clarity across the sampling seasons (p site 1 =.006, p site 2 = .009, p site 3 =.069).

When examining Bacoor Bay's TDS levels, the range of values detected at different sites–27.14 to 33.01 ppt at site 1, 26.02 to 36.41 ppt at site 2, and 26.77 to 36.63 ppt at site 3–signifies variations in dissolved matter content. The differences can be attributed to a combination of geological factors and human activities occurring within the bay's watershed. One key factor contributing to the TDS levels in Bacoor Bay is the intrusion of water from the Imus River. The Imus River serves as a conduit, originating from the upland city of Tagaytay and passing through several urban and densely populated areas before draining into Bacoor Bay. This course provides a path for a significant amount of dissolved matter to enter the bay. The sources of this matter are diverse and encompass residential, commercial, industrial, and agricultural activities along the river's path. Pollutants and waste generated in these areas can find their way into the river, ultimately reaching Bacoor Bay. On the other hand, salinity is simply the amount of dissolved salts in the water, and animals are often sensitive to changes in salinity. A salinity level determines the species composition of a given area and can affect the populations of certain species, causing them to decline or even go extinct, while other species may start to flourish (Sivapriya *et al*., 2022). Salinity levels across the sites show Site 1 consistently recording the highest levels (28.86 to 32.69 ppt), followed by Site 2 (27.28 to 31.56 ppt), and Site 3 (27.13 to 32.13 ppt). These variations could be attributed to differences in local hydrology and freshwater inflow (Jeppesen *et al*., 2023), as manifested by Site 1, situated farthest from the riverine systems originating in Cavite province. In terms of EC, Site 1 steadily displays the highest EC levels (47.16 to 53.22 mS/cm), followed by Site 2 (44.73 and 51.60 mS/cm) and then Site 3 (44.50 to 52.33 mS/cm). Electrical conductivity is closely linked to the concentration of dissolved ions and salts in water. Higher EC values generally correspond to higher concentrations of dissolved substances. The TDS, salinity, and electrical conductivity exhibit significant changes with seasonal variations ($p < 0.05$) based on the statistical analysis.

The provided pH measurements across all sites fall within the neutral range, suggesting relatively balanced acid-base environment. This was validated by the result of Friedman's two way ANOVA by rank indicating that there is no significant seasonal fluctuation in any of the sites (p site 1 =0.946, p site 2 = 0.598, p site 3 = 1.00). Throughout the study period, Site 3 exhibited the lowest dissolved oxygen levels, indicating a higher degree of pollution. Shanty houses in Site 3 lack proper sanitation infrastructure, leading to the discharge of untreated or partially treated sewage and wastewater directly into water bodies (du Plessis, 2022). This wastewater contains organic matter, nutrients, and pathogens. As this organic matter decomposes, bacteria consume oxygen during the process, leading to a reduction in dissolved oxygen levels. The higher the concentration of sewage and organic waste, the greater the demand for oxygen, leading to oxygen depletion (Aleruchi *et al.*, 2023). The slums lead to changes in the hydrology of water bodies, altering water flow, sediment transport, and habitat structure (Wei *et al.*, 2023). These changes can affect the natural processes that contribute to dissolved oxygen levels, such as mixing with atmospheric oxygen and the release of oxygen from aquatic plants. Significant seasonal variations in dissolved oxygen concentration were observed in site 1 ($p = .000$). Concentrations of dissolved oxygen is inversely proportional to BOD, thus high BOD levels can signify pollution and the presence of biodegradable organic materials. BOD values measured across the sites indicate that Site 3 has the highest levels, ranging from 5.00 ppm to 7.00 ppm, followed by Site 2 with measurements ranging from 2.00 ppm to 5.00 ppm, and Site1 with values ranging from 2.00 ppm to 4.00 ppm. Except for Site 2, there is no significant variation in BOD across the sampling seasons (p Site 1 =0.259, p Site 2 = 0.011, p Site 3 =0.727).

Site 2 recorded the highest nitrate levels among the three sites, likely due to the high concentration of mussels in this cultivation area. Mussels are filter-feeding organisms that extract nutrients, including nitrates, from the water column as they feed. While mussels can remove nitrates from the water through filtration, they also excrete waste, including nitrogen compounds, back into the environment (Geng *et al.*, 2022; Zieritz *et al.*, 2021). This can contribute to nutrient recycling and influence water nutrient levels. In areas like Site 2 with dense mussel populations or intensive aquaculture, the concentration of mussels can lead to localized nutrient accumulation. No significant seasonal fluctuation in BOD concentration was recorded in any of the sites (p Site 1 = 0.607, p Site 2 = 0.223, p Site 3 =0.115).

Phosphates are essential nutrients for aquatic life, but elevated phosphate levels can lead to eutrophication and other ecological imbalances (Feng *et al.*, 2023). Phosphate levels were lowest at Site 1, with moderate levels observed at Site 2, and the highest levels recorded at Site 3. This suggests that Site 3 receives higher inputs of phosphates, due to anthropogenic activities like agricultural runoff, sewage discharges, or industrial effluents. Human activities such as urbanization, and industrial processes introduce phosphates into water bodies through runoff, discharges, and improper waste disposal (Devlin and Brodie, 2023; Lukhele and Msagati, 2024). No significant seasonal fluctuation in BOD concentration was recorded in any of the sites (p Site 1 = 0.030, p Site 2 = 0.115, p Site 3 =0.513). Each site shows a distinct range of total coliform levels, suggesting differences in contamination sources or land use, local anthropogenic activities, and hydrological dynamics. Site 3 recorded the highest total coliform levels among the three sites which fall within the range of 130 MPN 100 m/L to 9200 MPN 100 m/L. The total coliform exhibits significant change with seasonal variations ($p < 0.05$) based on the results of Friedman's two-way ANOVA by rank test.

## *3.2. Abundance and Morphology of M. strigata*

Table 3 presents the seasonal abundance of *M. strigata* along with detailed morphological measurements. The table includes data on the mass (in mg), length, and width (in mm) of both the shell and the meat of *M. strigata*.

Table 3. Abundance and morphology of *M. strigata* in Bacoor and Manila Bay from September 2021-August 2022

| Parameters | Sampling Sites | Habagat (Southwest) | Amihan (Northeast) | | Summer (Intermonsoon) | | Habagat (Southwest) |
|---|---|---|---|---|---|---|---|
| | | Sept 2021 | Dec 2021 | Jan 2022 | Apr 2022 | May 2022 | Aug 2022 |
| Abundance | Site 1 | 5 | 0 | 1 | 0 | 0 | 233 |
| | Site 2 | 81 | 52 | 3 | 0 | 0 | 397 |
| | Site 3 | 21 | 5 | 6 | 0 | 0 | 132 |
| Mass of the whole mussel (mg) | Site 1 | 0.15 | 0 | 0.2 | 0 | 0 | 15.01 |
| | Site 2 | 1.69 | 1.94 | 0.6 | 0 | 0 | 31.82 |
| | Site 3 | 1.41 | 0.26 | 1.2 | 0 | 0 | 3.89 |
| Length of the shell (mm) | Site 1 | 11.80 | 0 | 13.9 | 0 | 0 | 24.27 |
| | Site 2 | 8.37 | 28.27 | 20.7 | 0 | 0 | 30.91 |
| | Site 3 | 25.25 | 13.94 | 22.52 | 0 | 0 | 16.38 |
| Width of the shell (mm) | Site 1 | 3.72 | 0 | 8.2 | 0 | 0 | 12.13 |
| | Site 2 | 1.69 | 10.35 | 11.23 | 0 | 0 | 14.77 |
| | Site 3 | 9.22 | 5.8 | 11.8 | 0 | 0 | 8.34 |
| Mass of the meat (mg) | Site 1 | 0.01 | 0 | 0.1 | 0 | 0 | 2.52 |
| | Site 2 | 0.37 | 0.37 | 0.03 | 0 | 0 | 5.91 |
| | Site 3 | 0.23 | 0.02 | 0.15 | 0 | 0 | 0.58 |
| Length of the meat (mm) | Site 1 | 5.84 | 0 | 10 | 0 | 0 | 5.41 |
| | Site 2 | 19.92 | 21.07 | 13.13 | 0 | 0 | 11.41 |
| | Site 3 | 18.47 | 10.26 | 15.52 | 0 | 0 | 11.53 |
| Width of the meat (mm) | Site 1 | 2.84 | 0 | 5.5 | 0 | 0 | 3.76 |
| | Site 2 | 6.84 | 8.37 | 8 | 0 | 0 | 6.66 |
| | Site 3 | 7.38 | 5.06 | 9.26 | 0 | 0 | 2.06 |

This data emphasizes notable seasonal variations in abundance, with all sites showing substantial increases by the end of the observation period, particularly during the “habagat” season or Southwest Monsoon of 2022, accounting to 233 individuals in site 1, 397 individuals in site 2, and 132 individuals in site 3. The morphology data of *M. strigata* indicates substantial growth in mass, length, and width across all sites also during

Southwest Monsoon. Site 2 exhibits the most significant increase, suggesting favorable conditions for growth and proliferation of this invasive mussel.

### *3.3. Environmental Factors Influencing the Abundance and Morphology of M. strigata*

Table 4 presents the Pearson Product Moment Correlation Coefficients between the abundance and morphology of *M. strigata* and various water quality parameters. The results indicate significant correlations between the abundance of *M. strigata* and TDS, salinity, and conductivity, all at the 0.01 level of significance. Furthermore, the morphological characteristics of *M. strigata*, including the mass, length, and width and the mass of the flesh, show significant correlations with these three parameters.

Table 4. Matrix of Pearson Product Moment Correlation between abundance and morphology of *M. strigata* and each environmental parameters

| Water Parameters | Abundance | *Morphology of M. strigata* | | | *Morphology of the Meat* | | |
|---|---|---|---|---|---|---|---|
| | | Mass | Length | Width | Mass | Length | Width |
| Temperature | .135 | .086 | .166 | .015 | .088 | .297 | .138 |
| Clarity | .091 | .097 | -.278 | -.314 | .103 | -.294 | -.288 |
| TDS | -.849** | -.743** | -.593** | -.577* | -.725** | -.304 | -.426 |
| Salinity | -.854** | -.747** | -.586* | -.576* | -.729** | -.287 | -.414 |
| Conductivity | -.849** | -.743** | -.587* | -.570* | -.725** | -.299 | -.419 |
| pH | -.337 | -.318 | -..38 | -.167 | -.300 | .300 | -.095 |
| DO | .256 | .282 | .056 | -.027 | .281 | -.100 | -.060 |
| BOD | -.031 | .141 | -.093 | -.121 | .164 | -.015 | -.125 |
| Nitrates | -.211 | -.184 | -.112 | -.169 | -.243 | -.001 | -.216 |
| Phosphates | .136 | .148 | .401 | .435 | .131 | .272 | .377 |
| Total Coliform | -.196 | -.232 | -.363 | -.419 | -.225 | -.181 | -.335 |

*Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

The table indicates that temperature, clarity and DO show generally weak correlations to abundance of morphological traits of *M. strigata*. Although the correlation is weak, there is a positive correlation between abundance and temperature (r = 0.135). Many invasive species are highly adaptable and can thrive in a range of temperatures, particularly higher ones that enhance their metabolic rates, reproductive success, and growth (Finch *et al.*, 2021; McKnight *et al.*, 2021). Warmer temperatures might reduce the resistance of native species, giving the invasive species a competitive edge. According to Brodsky *et al.* (2011), *M. strigata* exhibited reduced production of byssal threads under colder temperatures. Because byssal threads are essential for maintaining mussels' attachment to surfaces, their development is necessary for the establishment of mussels in particular habitats. Furthermore, these byssal threads act as a defense mechanism against possible predators by providing adhesion. Yuan *et al.* (2016) provided additional evidence for this conclusion by reporting that Mytella charruana showed decreased viability in cooler temperatures.

On the other hand, TDS, salinity, and conductivity, which are positively interrelated, consistently exhibit the strongest negative correlations with the abundance and morphological traits of *M. strigata*. Invasive species may experience stress from high salt levels, TDS, and EC, which can result in an osmotic imbalance and decreased abundance (Rivera-Ingraham and Lignot, 2017). Salinity can interfere with metabolism and water balance at concentrations above or below the isosmotic point of an organism's internal fluids. Low levels of TDS, salinity, and conductivity typically occur during the Southwest Monsoon, which is characterized by heavy precipitation. The influx of freshwater during this period dilutes dissolved solids and salts in the water column. In the study of Vallejo *et al.* (2017), the results showed that *M. strigata* can survive low salinities associated with increased freshwater run-off resulting from the southwest monsoon rainy season. On Luzon's western coast, this season runs from June to September. Since recruitment was seen during the first two months of the rainy season, it can be said that spawning and recruitment are triggered by the arrival of the rainy season. *M. strigata* demonstrates greater survival in environments with lower salinities, indicating a preference for invading estuarine areas with significant freshwater (Rice *et al.*, 2016;Yuan *et al.*, 2016).

The correlations between clarity, pH, DO, BOD, nitrate, and total coliform and the various metrics of *M. strigata 's* abundance and morphology are weak to moderate but not statistically significant. The weak nature of these correlations implies that these environmental influences are not strong and reliable indicators of the abundance or morphological characteristics of *M. strigata*. *M. strigata* has a wide range of adaptability with varying DO, BOD and pH ranges. *M. strigata* could survive waters with even low dissolved oxygen and high BOD, suggesting that this species has an invasive characteristic (Mediodia *et al.*, 2017). As an invasive species, *M. strigata* may primarily rely on its ability to outcompete native species for resources rather than sensitivity to DO, BOD, and pH levels, which may be less variable in its preferred habitats.

While phosphates appear to enhance the growth dimensions of *M. strigata*, their influence on the overall abundance of the species is minimal. The correlation coefficients for length and width are 0.401 and 0.435, respectively, indicating a moderate positive relationship. Phosphates can contribute to the formation of calcium phosphate, which is a component of the shells of mussels. Adequate phosphate levels can enhance shell strength and integrity, indirectly supporting better overall growth.

Table 5 presents the SPSS output displaying the correlations between selected water quality parameters and both the abundance and morphological characteristics of *M. strigata*.

Table 5. SPSS output displaying the correlations between selected water quality parameters and both the abundance and morphological characteristics of *M. strigata*

**Correlations**

| | | temperature | salinity | abundance | mass_M strigat | length_shell | width_shell | mass_meat | length_meat | width_meat |
|---|---|---|---|---|---|---|---|---|---|---|
| temperature | Pearson Correlation | 1 | -.436 | .135 | .086 | .166 | .015 | .088 | .297 | .138 |
| | Sig. (2-tailed) | | .070 | .594 | .734 | .510 | .954 | .730 | .231 | .585 |
| | N | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 |
| salinity | Pearson Correlation | -.436 | 1 | -.854** | -.747** | -.586* | -.576* | -.729** | -.287 | -.414 |
| | Sig. (2-tailed) | .070 | | .000 | .000 | .011 | .012 | .001 | .249 | .088 |
| | N | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 |
| abundance | Pearson Correlation | .135 | -.854** | 1 | .971** | .582* | .600** | .965** | .243 | .404 |
| | Sig. (2-tailed) | .594 | .000 | | .000 | .011 | .008 | .000 | .331 | .097 |
| | N | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 |
| mass_M.strigat | Pearson Correlation | .086 | -.747** | .971** | 1 | .564* | .597** | .999** | .201 | .377 |
| | Sig. (2-tailed) | .734 | .000 | .000 | | .015 | .009 | .000 | .424 | .123 |
| | N | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 |
| length_shell | Pearson Correlation | .166 | -.586* | .582* | .564* | 1 | .968** | .552* | .796** | .891** |
| | Sig. (2-tailed) | .510 | .011 | .011 | .015 | | .000 | .018 | .000 | .000 |
| | N | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 |
| width_shell | Pearson Correlation | .015 | -.576* | .600** | .597** | .968** | 1 | .580* | .690** | .865** |
| | Sig. (2-tailed) | .954 | .012 | .008 | .009 | .000 | | .012 | .002 | .000 |
| | N | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 |
| mass_meat | Pearson Correlation | .088 | -.729** | .965** | .999** | .552* | .580* | 1 | .202 | .362 |
| | Sig. (2-tailed) | .730 | .001 | .000 | .000 | .018 | .012 | | .422 | .139 |
| | N | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 |
| length_meat | Pearson Correlation | .297 | -.287 | .243 | .201 | .796** | .690** | .202 | 1 | .904** |
| | Sig. (2-tailed) | .231 | .249 | .331 | .424 | .000 | .002 | .422 | | .000 |
| | N | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 |
| width_meat | Pearson Correlation | .138 | -.414 | .404 | .377 | .891** | .865** | .362 | .904** | 1 |
| | Sig. (2-tailed) | .585 | .088 | .097 | .123 | .000 | .000 | .139 | .000 | |
| | N | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 |

While correlation shows the strength and direction of relationships between each environmental parameter and abundance of *M. strigata*, canonical correspondence analysis was done to explore further the species-environment relationships.

Figure 2 shows the ordination of the abundance of *M. strigata* from Bacoor and Manila Bay, Philippines around two main CCA axes. The plot features two axes (Axis 1 and Axis2) that represent the primary gradients in the data. Axis 1 accounts for 97.39% of the variance, with an eigenvalue of 0.244, while Axis 2 accounts for 2.43% of the variance, with an eigenvalue of 0.00609.

Variables such as pH, TDS, Salinity, EC, and BOD are aligned to the right, coinciding with the Northeast Monsoon season. This suggests that during this period, water quality parameters, which may be less directly affected by precipitation and runoff, wield significant influence over ecosystem dynamics. Southwest monsoon is associated with temperature and abundance, indicating higher temperatures and *M. strigata* abundance during this season. It is characterized by low TDS, low salinity, low EC. Intermonsoon is positioned on the right side of Axis 1, indicating a unique set of environmental conditions not strongly associated with abundance or any specific environmental parameters depicted in the plot. It is a transition period with balanced levels of most environmental factors. The CCA validates that abundance tends to decrease as salinity, EC, and TDS increase and temperature decrease, suggesting that areas with cooler temperature, higher salinity, EC, and TDS are less favorable for *M. strigata*.

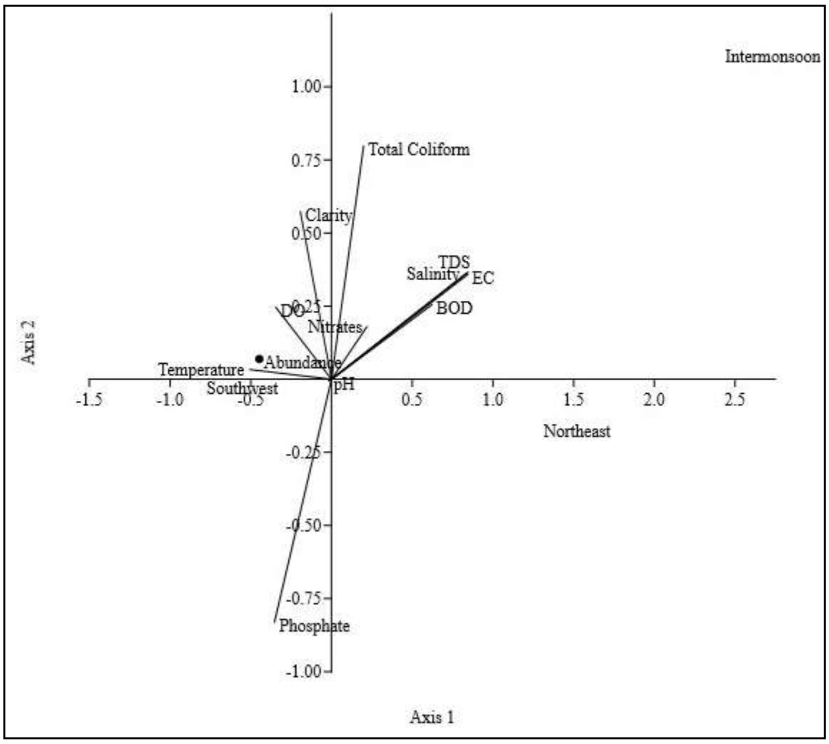


Figure 2. Canonical correspondence analysis of *M. strigata* abundance and environmental parameters in Bacoor and Manila Bay across different sampling seasons

Figure 3 shows the CCA biplot which illustrates the relationships between environmental variables and *M. strigata* abundance across three sites. Axis 1 and Axis 2 represent the primary environmental gradients influencing abundance of *M. strigata*. Axis 1 accounts for 90.39% of the variance, with an eigenvalue of 0.1296, while Axis 2 accounts for 7.04% of the variance, with an eigenvalue of 0.01009.

The *M. strigata* is dominant at Site 2, which is characterized by lower TDS, salinity, and electrical conductivity, as well as warmer water temperatures. The vectors suggest that total coliform, nitrates, and BOD are interrelated, but not strongly influencing the primary gradient of *M. charruana* abundance. Clarity, phosphate and DO are less influential in defining the species abundance, as indicated by their shorter vectors. These conditions create a favorable habitat for the mussels. The combination of these environmental factors reduce competition, enhance food availability, and support the M. *strigata*'s physiological needs, explaining their dominance in this particular site.

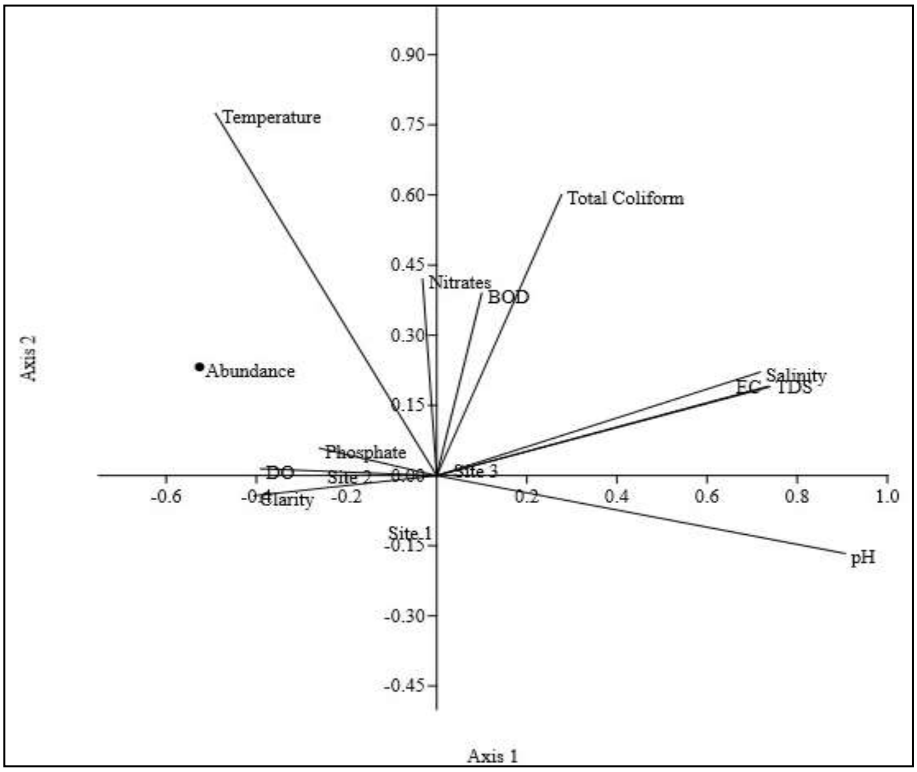


Figure 3. Canonical correspondence analysis of *M. strigata* abundance and environmental parameters in Bacoor and Manila Bay across different sampling sites

## *3.4. Relation between Anthropogenic Activities and Abundance of M. strigata*

The study was conducted in three distinct sampling sites emerged as strategic focal points, each predicated upon the level of anthropogenic influences. Site 1 is minimally disturbed with deep waters and *P. viridis* farming; Site 2 is near busy port facilities in Kawit and Cavite City which is recognized as the initial colonization of *M. strigata* mussels; Site 3, near residential areas, experiences significant anthropogenic activities. It was hypothesized that anthropogenic activities positively impact the proliferation of *M. strigata* by degrading water quality. To test this hypothesis, the water quality index was computed using equations 1 to 4 in section 2.2.1, then was correlated with the abundance of *M. strigata* using SPSS software.

Figure 4 provides a detailed illustration of the water quality index (WQI) for each site across various sampling seasons, emphasizing its relationship with the abundance of *M. strigata*. The significance of these correlations was evaluated using Pearson's Product Moment Correlation, with the results presented in the SPSS output, shown in Table 6. Furthermore, a summary of these findings, including key correlations, is provided in Table7.

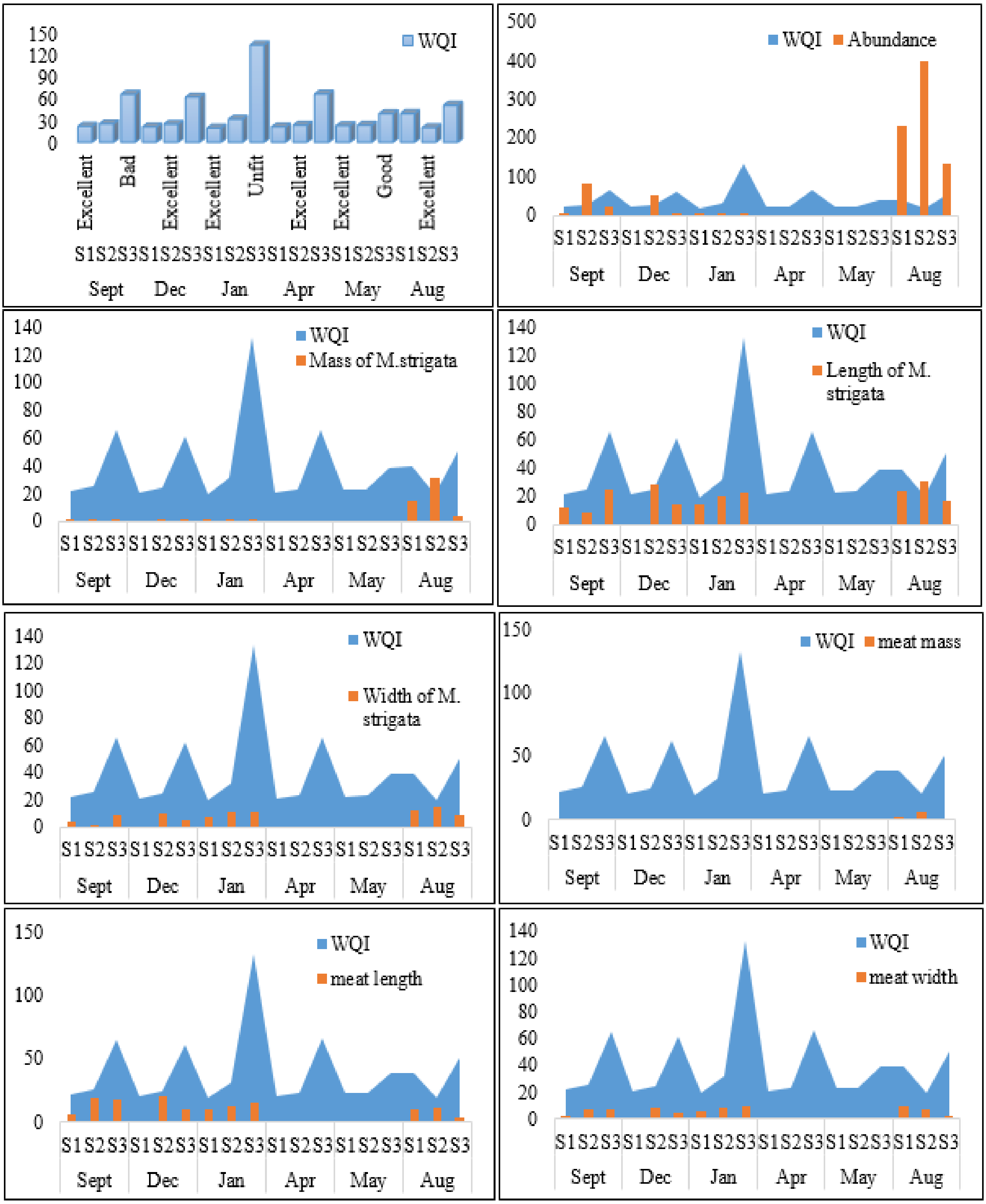


Figure 4. Graphical analysis of the relationship between water quality index, abundance, and morphology of *M. strigata*

Table 6 . SPSS output, illustrating the correlations between the Water Quality Index (WQI), the abundance, and the morphological characteristics of *M. strigata*

**Correlations**

| | | WQI | abundance | mass_M. strigata | length_shell | width_shell | mass_meat | length_meat | width_meat |
|---|---|---|---|---|---|---|---|---|---|
| WQI | Pearson Correlation | 1 | -.138 | -.126 | .269 | .304 | -.144 | .263 | .339 |
| | Sig. (2-tailed) | | .584 | .617 | .281 | .221 | .569 | .291 | .169 |
| | N | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 |
| abundance | Pearson Correlation | -.138 | 1 | .971** | .582* | .600** | .965** | .243 | .404 |
| | Sig. (2-tailed) | .584 | | .000 | .011 | .008 | .000 | .331 | .097 |
| | N | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 |
| mass_M.strigata | Pearson Correlation | -.126 | .971** | 1 | .564* | .597** | .999** | .201 | .377 |
| | Sig. (2-tailed) | .617 | .000 | | .015 | .009 | .000 | .424 | .123 |
| | N | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 |
| length_shell | Pearson Correlation | .269 | .582* | .564* | 1 | .968** | .552* | .796** | .891** |
| | Sig. (2-tailed) | .281 | .011 | .015 | | .000 | .018 | .000 | .000 |
| | N | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 |
| width_shell | Pearson Correlation | .304 | .600** | .597** | .968** | 1 | .580* | .690** | .865** |
| | Sig. (2-tailed) | .221 | .008 | .009 | .000 | | .012 | .002 | .000 |
| | N | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 |
| mass_meat | Pearson Correlation | -.144 | .965** | .999** | .552* | .580* | 1 | .202 | .362 |
| | Sig. (2-tailed) | .569 | .000 | .000 | .018 | .012 | | .422 | .139 |
| | N | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 |
| length_meat | Pearson Correlation | .263 | .243 | .201 | .796** | .690** | .202 | 1 | .904** |
| | Sig. (2-tailed) | .291 | .331 | .424 | .000 | .002 | .422 | | .000 |
| | N | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 |
| width_meat | Pearson Correlation | .339 | .404 | .377 | .891** | .865** | .362 | .904** | 1 |
| | Sig. (2-tailed) | .169 | .097 | .123 | .000 | .000 | .139 | .000 | |
| | N | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 |

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 7. Matrix of Pearson Product Moment Correlation for the water quality index, abundance, and morphology of *M. strigata*

| Parameters | r–value | p–value | Remarks |
|---|---|---|---|
| Abundance | -.138 | .584 | Not Significant |
| Mass of *M. strigata* | -.126 | .617 | Not Significant |
| Length of the shell | .269 | .281 | Not Significant |
| Width of the shell | .304 | .221 | Not Significant |
| Mass of the meat | -.144 | .569 | Not Significant |
| Length of the meat | .263 | .291 | Not Significant |
| Width of the meat | .339 | .169 | Not Significant |

Site 3 is heavily impacted by urban runoff, sewage discharge, and direct waste disposal from nearby residential areas, contributing significantly to its severe pollution levels. The water quality index is classified mostly "bad" water. On the other hand, Site 1 with minimal intervention from human activities aside from *P. viridis* farming received mostly "excellent" water quality index. The water quality at Site 2 consistently shows Good to Excellent ratings based on the WQI across the six sampling months. However, despite these favorable ratings, Site 2 is notable for hosting a significant population of *M. strigata*, characterized by high morphological diversity. This suggests that while the water quality index provides valuable insights into overall environmental conditions, it may not be the primary determinant influencing the abundance and morphology of *M. strigata* in this kind of ecosystem. Pearson Product Moment Correlation analysis indicated that there is no statistically significant correlation ($p > 0.05$) between the WQI, the abundance, and the morphology of *M. strigata*.

Table 8 and Figure 5 emphasize the seasonal spatial distribution patterns of *M. strigata* abundance. The data clearly illustrate significant patterns in the mussel's population dynamics.

Table 8. Distribution patterns of *M. strigata*

| Sampling Sites | Habagat (Southwest) | Amihan (Northeast) | | Summer (Intermonsoon) | | Habagat (Southwest) | Total (%) |
|---|---|---|---|---|---|---|---|
| | Sept 2021 | Dec 2021 | Jan 2022 | April 2022 | May 2022 | August 2022 | |
| Site 1 | 5 | 0 | 1 | 0 | 0 | 233 | 239 (26%) |
| Site 2 | 81 | 52 | 3 | 0 | 0 | 397 | 533 (57%) |
| Site 3 | 21 | 5 | 6 | 0 | 0 | 132 | 164 (17%) |
| Total | 107 | 57 | 10 | 0 | 0 | 762 | |
| Percentage | 93% (including Aug 2022) | 7% | | 0% | | | |

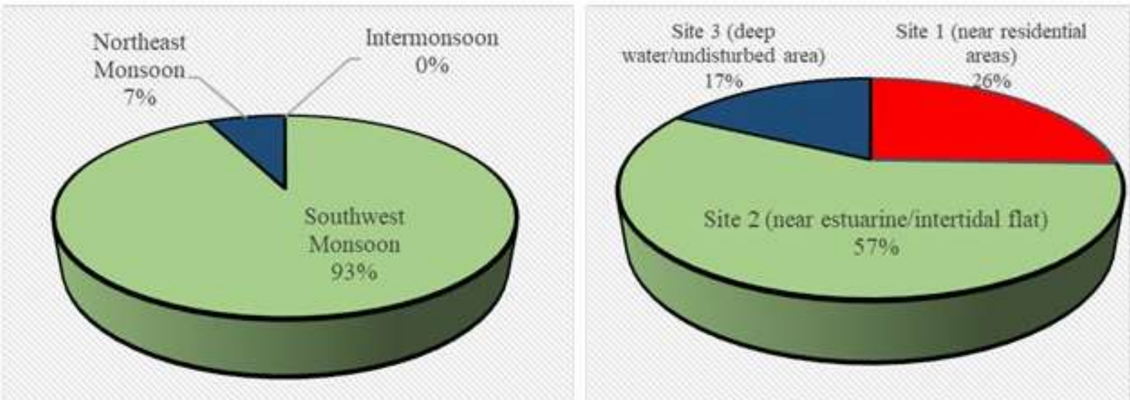


Figure 5. Distribution patterns of *M. strigata* abundance

During the Southwest Monsoon, *M. strigata* exhibits a remarkable increase in abundance, achieving a peak of 93%. Across different sites, Site 2 stands out with the highest *M. strigata* abundance, registering 57%. Certain locations near Site 2, such as the Cavite City and Kawit Cavite, maintain consistently low salinity levels below 30 ppt even during the peak of the hot, dry Philippine summer. These conditions provide ideal habitats for the year-round survival of *M. strigata*. The intertidal flat along these areas are recognized as one of the initial colonization sites for *M. strigata*, benefiting from low salinity levels that support their thriving throughout the year. During the occurrence of Southwest Monsoon, *M. strigata* larvae disperse to neighboring areas of Bacoor and Manila Bay, facilitated by longshore currents. This seasonal hydrological pattern plays a crucial role in the natural spread of *M. strigata* to nearby waters, significantly contributing to their regional distribution. Despite the proximity of Site 3 to the urban centers of Cavite City and Kawit, the site is shielded by a natural landform that effectively buffers it from the strong water currents emanating from these areas.

## Conclusion

In conclusion, the dominance of *M. strigata* during the Southwest Monsoon highlights its preference for specific water quality parameters and temperature conditions. Lower TDS, salinity and electrical conductivity alongside warmer water temperatures are conducive to the proliferation of *M. strigata*. The geographical distribution of *M. strigata* is significantly shaped by larval dispersal facilitated by longshore currents during the Southwest Monsoon. During this period, the larvae of *M. strigata* are carried by the currents to neighboring areas. The extent of colonization is influenced by the proximity and exposure of these areas to the intertidal flat from which the species initially colonized. Areas closer to the original colonization site and more directly exposed to the longshore currents tend to experience greater colonization by *M. strigata*, highlighting the role of hydrodynamic factors in determining the species' distribution.

Anthropogenic activities impacting the water quality index do not appear to be the primary determinant influencing the abundance and morphology of *M. strigata*. Among the three sites, Site 3 stands out as the most heavily impacted by urban runoff, sewage discharge, and direct waste disposal from the surrounding residential areas. These anthropogenic activities contribute significantly to the site’s severe pollution levels, negatively affecting the local ecosystem. In contrast, Site 1, which experiences minimal human intervention aside from the farming of *P. viridis*, maintains relatively better environmental conditions. Despite this, both Site 1 and Site 3 do not support a significant population of *M. strigata*, suggesting that factors beyond human activity, such as water quality and habitat suitability play a critical role in determining the distribution of this species.

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