Mangrove Habitat Structure of Mud Crabs (*Scylla serrata* and *S. olivacea*) in the Bee Jay Bakau Resort Probolinggo, Indonesia

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Abstract

Mud crabs (Scylla serrata and S. olivacea) are important fisheries resources, but their population in nature is decreasing due to anthropogenic activities, like the deforestation of mangrove forests. Hence, it is crucial to conserve this marine biota for future sustainable use and to conserve our marine biodiversity. Conducting studies on the biological interactions of mud crabs in mangrove habitats can be one of the future conservation approaches. Accordingly, an analysis of the functional relationships between Scylla spp. abundance and the respective mangrove habitat have to be carried out. The research was conducted in the mangrove ecosystem of Bee Jay Bakau Resort Probolinggo (BJBR). Data were collected using line transects and quadrant transects. The Associations between mangroves and mud crab habitat structures were analyzed using the Correspondence Analysis (CA) method. The results show that the relationship matrix between Scylla spp. and the structure of the mangrove habitat is centered on the F1 and F2 factorial axes (89.22%). S. serrata of all size classes were associated with dense mangroves (≥15 trees per 100m²) and high salinities (3-4 ppt), while S. olivacea has shown to be associated with rare to very dense mangrove systems. It indicates that S. olivacea tends to have a higher adaptation rate than S. serrata in this mangrove system. This study will provide information and recommendation for the conservation management of mud crabs and mangrove ecosystems to conserve marine biodiversity.

Keywords: *Scylla serrata, S. olivacea, Conservation, Mangrove Systems, Correspondence Analysis,*

Introduction

Mud crabs of the genera *Scylla* belong to the Portunidae family and are widely distributed throughout the Indo-West Pacific mangrove ecosystems (Trivedi and Vachhrajani, 2013). These mud crabs have a high commercial value because of their savory taste and high nutritional contents (Pratiwi, 2011). The nutritional content consists of 44.85-50.58% protein, 10.52-13.08% fat, and 3.579-3.724 kcal/g energy (Karim, 2005); therefore, with increasing human populations, the demand for mud crabs has been growing in recent years. Currently, the population of *Scylla* spp. in natural systems seems to decline due to mangrove forests' deforestation (Ulfa *et al.,* 2018) and degradation. Ismail *et al.* (2019) stated that the catch of mud crabs in the Segara Anakan area between 2010-2017 decreased compared to those observed in 1991 (estimated 158.92 tons.y^{-1}), and this could be probably due to the substantial decrease in the mangrove ecosystem area in general (from 12,592ha in 1991 to 8,036ha in 2016). Indonesia's mangroves have been deforested about 25-30% of the total area since 1980 (FAO, 2007). Deforestation causes the quality and potential of the mangrove ecosystem to decline (Saputri and Muammar, 2018).

Mangroves are tropical coastal vegetation areas that can develop and grow well within tidal systems (Bengen, 2001). Mangrove ecosystems are fundamental habitats for mud crabs because they function as a feeding ground, nursery ground, and spawning ground for various organisms (Jacobs *et al.*, 2019). Pratiwi (2011) stated that all life stages of male mud crabs stay within the mangrove ecosystem while the female mud crabs migrate to the sea for spawning. Based on this description, it is highly assumed that the whole life of the different *Scylla* spp. depends upon healthy mangrove ecosystems (Bunting *et al.,* 2018), and they need to be monitored regularly for better management.

Several parameters of the mangrove ecosystem and its environment, such as mangrove

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https://ejournal.undip.ac.id/index.php/ijms
DOI: 10.14710/ik.ijms.27.2.124-132
Received : 29-01-2022
Accepted : 08-03-2022

vegetation, salinity, temperature, substrate, tides, and topography can affect the existence and distribution of *Scylla* spp. Mangrove density is directly corresponding to the abundance of *Scylla* spp. (Putra *et al.,* 2016). *Scylla* spp. are euryhaline organisms in a wide salinity range (2-60ppt). Temperature conditions (20-30°C) and muddy substrates are very important for the survival of the different *Scylla* species, especially for the molting phase (Alberts-Hubatsch *et al.,* 2016). The foraging behavior of the mud crabs is strongly influenced by tides and the topography of the respective habitat (Sara *et al.,* 2014).

The declining population of mud crabs requires better management and conservation efforts in the respective areas to make more sustainable use of these resources and protect marine biodiversity. Understanding the species biodiversity in a particular habitat will help enhance the management of these crab populations and allow more precise stock assessments. A diversified and balanced population of species exists in a healthy environment to maintain the ecosystem's equilibrium. All species in an ecosystem depend on one another, directly or indirectly. Thus, it is critical to maintaining a high species diversity to create a more efficient, productive, and sustainable marine ecosystem (Gamfeldt *et al.*, 2008)

For better conservation of the crabs, a study on the biological interactions between *Scylla* spp. and the structure of the mangrove ecosystem as their habitat is urgently needed as a reference for future management strategies. Studies related to mud crabs, such as Sara *et al*. (2014) in Lawele Bay, Southeast Sulawesi, on the habitat of the mud crab (*S. serrata*), which has been classified based on similarities in salinity, turbidity, substrate, mangrove vegetation, and intertidal topography, and Redjeki *et al*. (2020) Co-existence between *Scylla serrata* and *Scylla transquebarica* in the lagoon of Segara Anakan, Cilacap, Indonesia. According to Chadijah and Wadritno (2013), the abundance of mangrove crabs (*S. olivacea*) was influenced by the density of mangrove vegetation and water quality parameters (such as salinity, pH, and temperature). Unthari *et al*. (2018) explained that mud crabs (*Scylla* spp.) in the Bungin River, Banyuasin, were mostly found in areas with muddy substrates. Previous studies were mostly conducted in deforested mangrove areas and rarely in rehabilitated mangroves. Meanwhile, rehabilitated mangrove areas are potential areas as natural habitats for mud crabs, but research in these areas is scarce.

The Bee Jay Bakau Resort (BJBR) is an 89 hectares of mangrove ecotourism area located in the center of Probolinggo, East Java (Nugroho *et al*., 2018). Previously, BJBR could be considered as a damaged mangrove ecosystem by human activities, such as the felling of mangrove trees, waste disposal sites, and destruction of mangroves. Therefore, efforts to rehabilitate the mangroves have been carried out. Mangrove rehabilitation is expected to increase the mangrove density. A high density of mangroves affects the availability of food sources for various biota, including mud crabs (Kamaruddin *et al*., 2019).

The biological information and knowledge on the zoogeographical distribution of mud crabs are needed as a basis for enhanced conservation management for these crabs and mangrove ecosystems. The purpose of this study was to analyze the functional relationships between *Scylla* spp. and the structure of the mangrove ecosystem in The Bee Jay Bakau Resort (BJBR) Probolinggo.

Materials and Methods

The study was conducted in Bee Jay Bakau Resort (BJBR), Mangunharjo, Mayangan, Probolinggo, East Java (Figure 1.). The determination of the study site was based on previous research, like a study on the Contribution of Mangrove Ecosystems to Primary Productivity of Coastal Waters in The Beejay Bakau Resort, Probolinggo (Salma, 2021). The study site was divided into three different stations, and each research station had 3 substations according to the density level of the mangrove ecosystem.

According to Salma (2021) Station 1 can be considered as a mangrove rehabilitation area with density of 9 to 56 individuals per 100m^2 of mangrove species with relatively the same tree height between *Avicennia marina, Rhizophora mucronata,* and *R. stylosa.* In the middle and back zone of those area were subjected to water pollution derived from the estuary of the Banger River. Station 2 is a rehabilitated mangrove area (at the front and middle zone) and a natural habitat area at the back with some damage due to human activities. The front zone is only covered by *A. marina*, while the other zones are covered by *A. marina* and *R. mucronata*. This area has a mangrove density ranging from 10 to 22 individuals per 100m^2. Station 3 is a natural mangrove area with a high density (24 to 36 individuals per 100m^2) of *A. marina* and *R. mucronata* but also suffered damage, especially the front zone. The salinity of the mangrove ecosystem areas ranges from 1.9-4.0 ppt, and the back zone showed lower values (1.9ppt and 2.1ppt) because it is influenced by freshwater runoff from the Banger river. While the temperature was ranged from 29.4-32.9°C depending on the

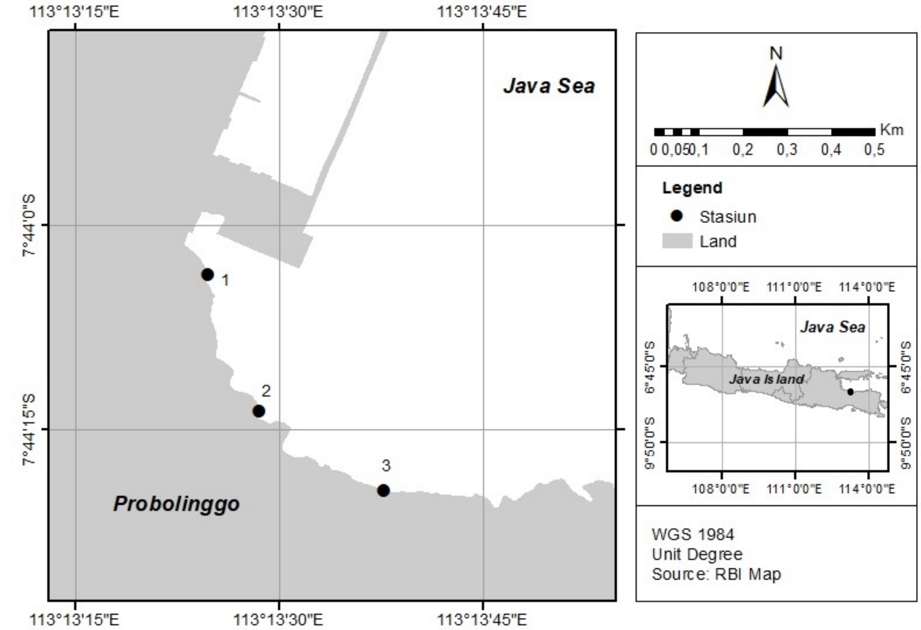

Figure 1. Study site in the mangrove ecosystem of the Bee Jay Bakau Resort, Probolinggo

mangrove cover in each substation, and pH ranges from 7.72-8.83.

Scylla spp. Samples were collected from all substation areas using a line transect. Each line transects had 3 quadrant transects of 10m x 10m and distance between the transect was 20m. The line transect was placed perpendicular to the shoreline, and the first transect was located in the first vegetation found (Katili *et al.*, 2017). At each quadrant transect, 6-8 folding traps (40cm x 29cm x 15cm) were placed during low tide and inspected at low tide on the next day. The duration of catching time was 2-4 days at each location (Bonine *et al.*, 2008). Afterward, the samples of *Scylla* spp. obtained were measured, and the number of individuals, body weight, and carapace width were observed. The substrate parameters were measured, including fraction and total organic matter (TOM).

Data analysis

The examined mud crabs (*Scylla* spp.) were identified according to a key provided by the Ministry of Maritime Affairs and Fisheries (2016) by examining their differences on the frontal spines and the corpus. The abundance of *Scylla* spp. is known through the number of mud crabs found at the research site. The determination of the carapace width size class was based on Walpole (1992). The size class of each species was divided into three different classes, i.e. small, medium, and large size. The relationships between mud crabs and structural characteristics of the mangrove habitat of BJBR were analyzed using the Correspondence Analysis (CA) method (Bengen, 2000).

Result and Discussion

The abundance and morphology of Scylla serrata and S. olivacea

The mud crabs from the BJBR mangrove ecosystem have been identified as *Scylla serrata* and *S. olivacea*. The total number of two crab species was 41 individuals (Figure 2.). The mud crabs found were spread throughout the research substations, and most of them originated from the front zone of the examined mangrove ecosystem.

S. serrata is a red to orange mud crab (especially in the chelae) with a sharp and high frontal spine, and it has spines on its corpus. The species *S. serrata* has been found in as many as 10 individuals and was found only in the substations 1.1; 1.2; 2.1; 3.1; and 3.2 (the front and middle zones). They were only found in the front and middle zones of the mangrove ecosystem since they have got high density of the mangrove trees with the minimum level of damage. The existence of a species depends on the level of tolerance and sensitivity of the individual to its environment (Siahaan *et al.,* 2018). The highest abundance of *S. serrata* was located at substation 1.1. This mud crab

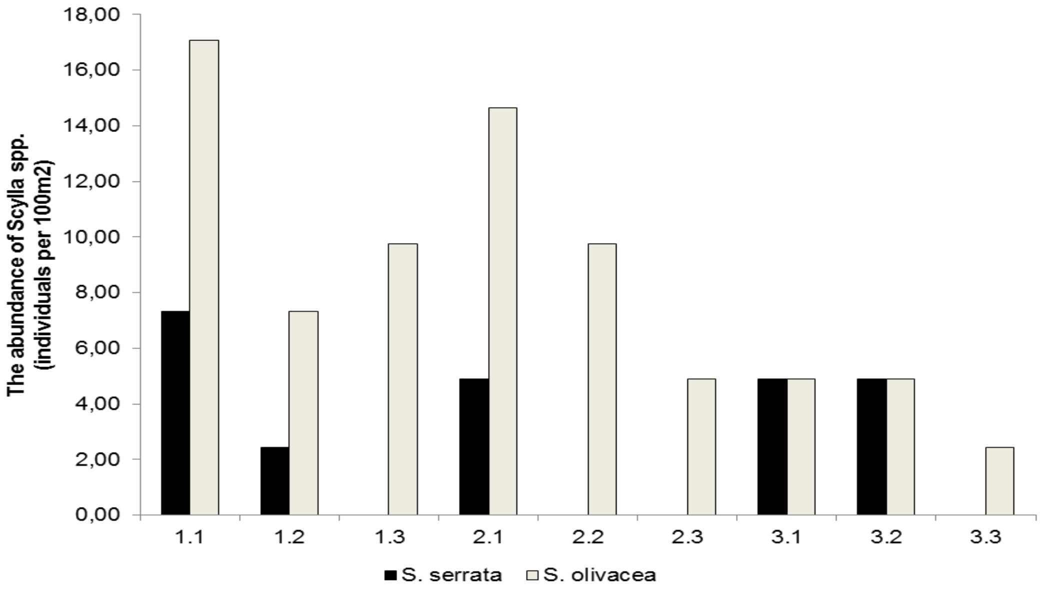

Figure 2. The abundance of *S.serrata* and *S. olivacea* in the BJBR mangrove ecosystem

species has a carapace width ranging from 43.2-80.8mm (Figure 3).

S. olivacea has got green to gray with a sloping frontal spine with spines on the corpus. The total number of *S. olivacea* found in all substations was 31 individuals. These mud crabs were found at all substations, with the highest abundance in substation 1.1. The carapace width of *S. olivacea* ranged from 31.3-67.8mm (Figure 3.). The results of size classes showed that *S. olivacea* had a wider distribution and higher abundance than *S. serrata*. It is because *S. olivacea* has a higher environmental tolerance level than *S. serrata* (Putra *et al.*, 2016). Baylon (2013) stated that *S. olivacea* could survive at lower salinities than *S. serrata* and another related species *S. tranquebarica*, with a survival rate of 95% for megalopae stages. Walton *et al.* (2006) proved that areas with low salinity showed a higher abundance of *S. olivacea* than *S. serrata*. Another assumption related to the low abundance of *S. serrata* in this area is overexploitation of *S. serrata*.

The highest abundance of *S. serrata* and *S. olivacea* was at substation 1.1., i.e., the area with the highest mangrove density (56 trees per 100^2) and is dominated by *A. marina*. Areas with a high density of mangroves can produce a lot of fallen litter (Bengen, 2001). Mangrove litter is a food source for juvenile mud crabs (Pambudi *et al.,* 2019). Besides that, mangrove litter is also a food source for gastropods, herbivorous fish, and shrimp which are food for larger juveniles mud crab (Alberts-Hubatsch *et al*., 2018). Mangrove crabs with large sizes tend to choose habitats with high mangrove densities for their food source (Siringoringo *et al*., 2017). Mulya (2019) stated that the growth of mud crabs would be faster if they are in habitats with sufficient food availability, such as detritus, plankton, and benthic organisms.

The measurement of the carapace width of the mud crab showed that the sampled specimens had small sizes, ranging from 3.13-80.80mm. The result of present works also revealed that *Scylla* spp. in the BJBR area were mainly in the early juvenile stage (carapace width <70mm) and the larger juvenile stage (70mm to 120mm) (Sara, 2010). The carapace width of the examined mangrove crabs in the BJBR mangrove ecosystem tends to be small compared to other areas. Kumalah *et al*. (2017) state that the mud crabs' carapace width (*Scylla* spp.) in Subang City ranged from 56-125mm. The causes of the small size of the carapace width were, on the one hand, due to the time of catching the crabs at the end of the rainy season or the beginning of the dry season. During this time, juvenile crabs migrate from the sea to the mangrove ecosystems (Tiurlan *et al*., 2019). Other factors were the high rate of utilization of the mud crab itself (Sara, 2010), habitat conditions related to food availability, as well as temperature, and salinity (Wijaya *et al.,* 2010). Siahainenia (2008) postulated that if young mud crabs dominate an area which was the case in the present study, this condition indicates a rapidly growing population. Otherwise, if the adult category dominates an area, the area's population is assumed to be stationary.

Mangrove habitat structure

According to the Ministry of Environment and Forestry (2004), the mangrove density in the BJBR

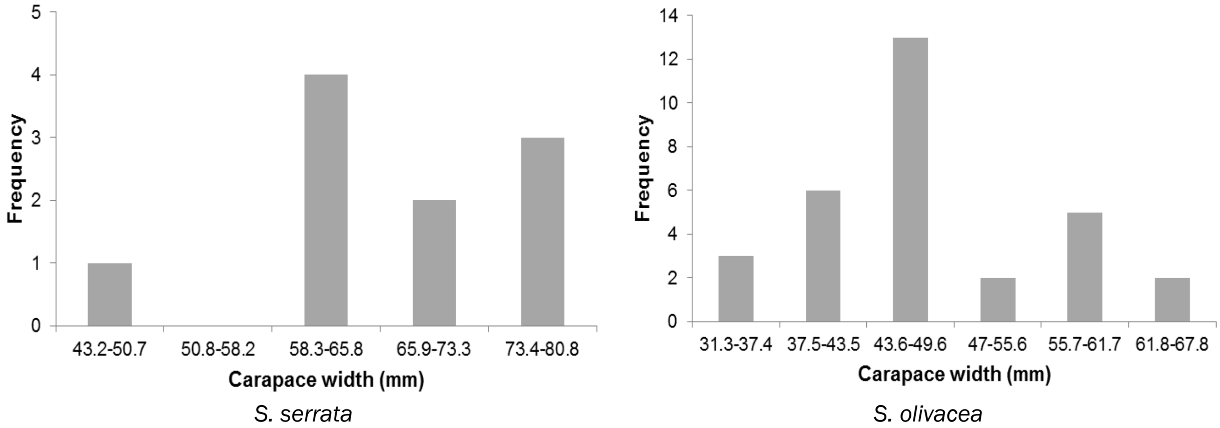

Figure 3. Frequency of the class sizes of *Scylla* spp. in the BJBR mangrove ecosystem

mangrove ecosystem is classified into 3 groups, namely: low (<10 trees per 100m^2), high (≥10-<15 trees per 100m^2), and very high (≥15 trees per 100m^2). Substation 1.3 had a low mangrove density and substations 2.2 and 2.3 had a high density, whilst the other substations had a very high density. *A. marina* was the dominant mangrove species at all stations because they are able to well adapt to extreme conditions. *A. marina* grow in varied salinity, i.e. from freshwater conditions with low salinities (0 ppt) up to 90ppt (Susanto *et al.,* 2013).

The growth and development of *Scylla* spp. are also influenced by the water conditions of the mangrove ecosystem (Kumalah *et al*., 2017). Based on Salma (2021), the water quality of the mangrove ecosystem indicates that the BJBR area is suitable for the survival of *S. serrata* and *S. olivacea*. The temperatures were 29.4-32.9^{o}C which were suitable for the growth of mud crabs. Mud crabs are eurythermal species that tolerate temperatures ranging from 12-35^{o}C (NSW-DPI, 2007). Mud crabs can still survive in low salinities (0-4ppt), and they can adapt to salinities below 10ppt (Unthari *et al.,* 2018) or even less with a broad range (0-34ppt) (Saputri and Muammar, 2018) because they are euryhaline. According to Siahainenia (2008), the pH value obtained from all sampling stations was classified as good (6.5-7.5) and very good (7.5-9). Substation 3.1 is an area with a good pH value, while the other substations were classified as areas with very good pH conditions. Tahmid *et al*. (2015) added that the pH value in the mangrove ecosystem of Bintan Bay is good (6.65-7.20). This condition supports the survival of mud crabs.

The sediment granulometry analysis results revealed that the mangrove ecosystem of BJBR has a clay substrate texture (Table 1.). The proportion of clay content in the substrate ranged from 71.01 to 80.3%, while sand had a proportion of 9.9 to 17.8%, and silt had a proportion of 9.7 to 12.3%. According to Tahmid *et al.* (2015), mud crabs tend to choose a fine substrate such as clay since it is easier to dig their burrows. Mangrove crabs dig burrows to immerse themselves in the substrate to avoid predators, especially during molting (Saputri and Muammar, 2018). In addition, areas with smooth substrates are indicated to have high organic matter content (Avianto *et al*., 2013).

The TOM content in the BJBR mangrove ecosystem ranged from 1.71-2.74% (Table 1). It is relatively low compared to other areas. Budiasih *et al*. (2015) stated that the TOM of the mangrove ecosystem of Timbulsloko Village, Demak ranged from 10.087-16.073%. The low TOM value in all examined substations is the minimal amount of litter generated. The organic material comes from fallen leaves, twigs, and even fruits, which were later decomposed by bacteria (Lestaru *et al*., 2018).

The highest TOM content in the BJBR mangrove ecosystem was at substation 1.1 (2.74%). Substation 1.1, with high organic matter content, is, therefore, suitable habitat for biota such as mud crabs (Masterson, 2007). The organic matter will support the growth of several biotas, such as gastropods, one of the food items for mud crabs (Avianto *et al*., 2013).

Relationship between Scylla spp. and mangrove habitat structure

Figure 4 shows the relationship between *Scylla* spp. and the structure of the mangrove habitat in the Bee Jay Bakau Resort area. It was centered on two main axes, namely the F1 and F2 factorial axes. The total percentage of relationships (F1 and F2) was 89.22%, with the F1 factorial axes of 68.29% and the F2 factorial axes of 20.93%. The CA analysis showed four groups of associations between *Scylla* spp. and its mangrove habitat structure based on size class. The first group, namely the association between medium sized *S. Serrata,* was associated with temperatures (31.8-32.9^{o}C), salinity (0-1.5ppt), and TOM (1.4-1.8%). The second group visualized the association of medium sized *S. olivacea* with salinity (1.6-4.5ppt) and TOM (1.9-2.8%). The third group displays the association between small sized *S. olivacea* and the mangrove density (<10 trees per100m^{-2}), (≥10-<15 trees per 100m^{2}), temperature (29.4- 30.5^{o}C), and pH (7.8-8.9). The fourth group shows the association between small and large sized *S. serrata*; large *S. olivacea*, and the mangrove density (≥15 tresses per 100m^{-2}), temperature (30.6-31.7^{o}C), and pH (7.2-7.7). It indicates that the presence of large *S. serrata* and *S. olivaceae* is closely related to the density of mangroves. The mangrove crab's existence is determined by appropriately managing mangrove habitats as a breeding sites for them (Dayal *et al.,* 2019). Well-managed mangrove habitats can support healthy development of mud crab. Mangrove trees with a thick canopy and a high diameter thrive well. The number of leaves is directly proportionate to the size of the canopy (Unthari *et al*., 2018). Because of the thick canopy, numerous leaves and a growing amount of trash falls to the forest floor. Mud crabs eat debris that falls on the forest floor as one of their natural diets. Dumas *et al.* (2012) stated that mud crabs are often connected with healthy mangrove ecosystems; hence the better the mangrove region is managed, the more mud crabs will live in the respective area.

The results of the Correspondence Analysis showed that *S. serrata* of all sizes have been associated with areas of very high mangrove density (≥15 trees per 100m^{2}) and low salinities (3-4ppt). It contrasts with *S. olivacea*, which prefers to inhabit. In mangrove ecosystems with low to very high mangrove densities. It indicates that *S. olivacea* tends to have a higher adaptation rate in terms of its adaptability to low salinities than *S. serrata*. Low salinity is a condition that is not considered an

Table 1. Substrate texture and Total Organic Matter of the BJBR mangrove ecosystem

Sub Station	Substrate Fraction			Substrate Texture	TOM
	Sand (%)	Silt (%)	Clay (%)		
1.1	11.9	12.3	75.80	Clay	2.74
1.2	11.6	11.5	76.87	Clay	2.10
1.3	9.9	9.7	80.30	Clay	2.08
2.1	16.6	9.98	73.40	Clay	1.91
2.2	16.3	10.1	73.60	Clay	2.33
2.3	17.8	11.1	71.01	Clay	2.04
3.1	15.3	11.2	73.50	Clay	1.89
3.2	15.3	12.5	72.30	Clay	1.71
3.3	16.1	11.3	72.60	Clay	1.49

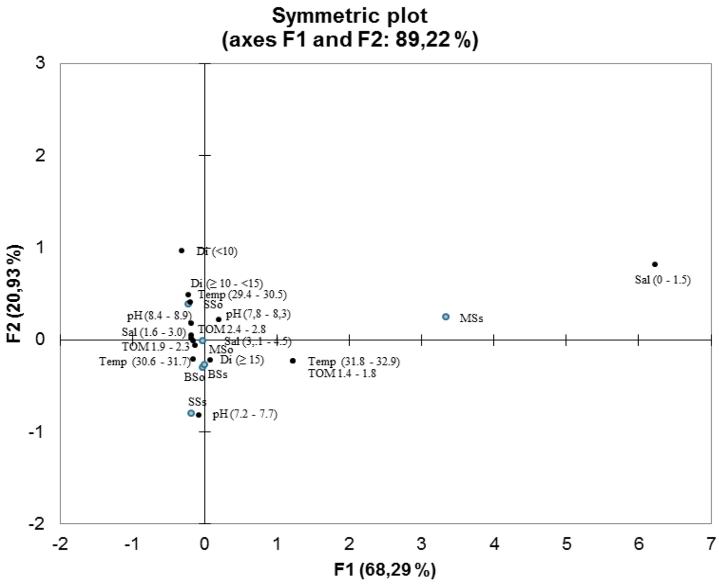

Figure 4. Correspondence Analysis (CA) between *Scylla* spp. based on size class and mangrove habitat structure of BJBR

optimum for crab growth. The results of Mia and Shah (2010) showed that increasing salinity significantly affected the survival and growth of mud crabs. These results also have similarities to the study by Putra *et al.* (2016) in a mangrove rehabilitation area. Furthermore, *S. serrata* and *S. olivacea* abundance were characterized by the content of TOM. The higher the TOM concentration, the higher the abundance of the crabs. The TOM value derived from the litter decomposition greatly affects food availability (Yulma *et al.*, 2013), so it has an enormous impact on the abundance of mud crabs in an area. According to Siahaan *et al.* (2018), the pH value and water temperature also affect the presence of mud crabs of all sizes, which is in line with the present study. Abiotic variables such as rising temperatures enhance the metabolism of the mud crab because increased evaporation causes the soil substrate to dry up, making it harder for the mud crabs to mate and molt. As a consequence, the mud crabs will often die. This will undoubtedly decrease the number of mud crabs (Skilleter and Warren, 2000). The influence of acidity (pH) provides critical information about changes that occur in waterways, not only as a result of the addition of acidic or basic materials but also as a result of indirect changes in the metabolic activity of aquatic biota. Acidity may enhance the existence of decomposing organisms that degrade organic debris that accumulates in the mangrove ecosystem, increasing the acidity of the mangrove soil. Generally, the higher the pH value, the quicker the organic matter created by the litter material demineralizes, producing a higher abundance of organic matter for the requirements of mud crabs (Kamaruddin *et al.,* 2019).

Conclusion

The survival of the two examined species *Scylla serrata* and *S. olivacea* is influenced by the structure of the mangrove habitat. CA analysis showed that *S. olivacea* had a better ability to adapt to extreme conditions (such as low salinity) than S *serrata*. The mud crabs have large carapace widths (medium to large sized) tended to inhabit in high mangrove densities and high TOM contents area. The biological information of the different crab species and the knowledge of their zoogeographical distribution in an area can be used as a database for managing and conserving mangrove crabs and the location of mangrove planting. It is recommended that a site-specific approach to the planting location should be applied, which aims to optimize the area around the substation 1, especially in the front zone of the examined mangrove, to enhance and conserve mud crab population health in the future.

Acknowledgment

The authors would like to thank Bee Jay Bakau Resort Probolinggo as a facilitator for the implementation of the research.

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