International Journal on Advanced Science Engineering Information Technology

Vol.12 (2022) No. 2
ISSN: 2088-5334

Correlation of Environmental Factors With Population of Horseshoe Crab (*Tachypleus gigas*) in Sedati Waters, Sidoarjo District

Oktavian Vernanda [a], Luthfiana Aprilianita Sari [b,*], Yudi Cahyoko [b], Sulastri Arsad [c], Kustiawan Tri Pursetyo [d], Nina Nurmalia Dewi [b], Saleem Mustafa [e]

[a] *Program Study of Aquaculture, Faculty of Fisheries and Marine, Universitas Airlangga, Surabaya, 60115, Indonesia*
[b] *Department of Aquaculture, Faculty of Fisheries and Marine, Universitas Airlangga, Surabaya, 60115, Indonesia*
[c] *Department of Aquatic Resources Management, Faculty of Fisheries and Marine Science, Universitas Brawijaya, Malang 65145, Indonesia*
[d] *Faculty of Fisheries and Food Science, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia*
[e] *Borneo Marine Research Institute, Universiti Malaysia Sabah, Locked Bag 2073, 88999 Kota Kinabalu, Sabah, Malaysia*
*Corresponding author: *luthfianaas@fpk.unair.ac.id*

***Abstract*—Horseshoe crabs (*Tachypleus gigas*) in local called Mimi are coastal animals belonging to the *Limulidae* family. The horseshoe crabs live at the bottom of calm coastal waters and river estuaries with sandy and muddy bottoms. The decrease in the population number of horseshoe crabs in nature could be caused by habitat degradation, including coastal abrasion, ecosystem damage, and the death of natural resources in the waters. This study aims to determine the correlation of environmental factors with the population of Horseshoe Crab (*Tachypleus gigas*) in Sedati waters, Sidoarjo District. This type of research was exploratory with data analysis using linear regression and simple correlation. Moreover, the sampling was carried out by purposive random sampling at predetermined points of the station in Sedati Waters, Sidoarjo District. The results show that the average density in October was 0.08 ind/m2, in November was 0.05 ind/m2, and in December was 0.05 ind/m2. Moreover, the correlation between the horseshoe crabs and water quality is noted in the current of 58%, transparency of 37%, and DO of 33%. Based on the results of this study, the environmental factors including transparency, currents, and DO have a strong correlation on the horseshoe crab population in Sedati waters, while pH, ammonia, carbon, and microfauna parameters have a quite influential effect on the population of horseshoe crabs.**

***Keywords*—Marine; biodiversity-inclusive; coastal habitat; trophic level; nutrient runoff.**

Manuscript received 17 Apr. 2021; revised 11 Sep. 2021; accepted 9 Nov. 2021. Date of publication 30 Apr. 2022.

I. INTRODUCTION

Horseshoe crabs (*Tachypleus gigas)* in Indonesia, especially on the island of Java, are commonly referred to as *Mimi*, coastal animals belonging to the *Limulidae* family. Currently, there are only four types of horseshoe crabs that can be found in the world [1]. *Limulus polyphemus* species are only found on the Atlantic coast of North America, and the three other types of horseshoe crabs are found in Asia, namely *Tachypleus tridentatus*, *Tachypleus gigas,* and *Carcinoscorpius rotundicauda*. However, the existence of these three species in Asia has been to be in deficit status [2]. Horseshoe crabs in Indonesia are considered primitive marine animals and are grouped into the category of vulnerable or rare animals [3].

The decrease in the population number of horseshoe crabs in nature can be caused by habitat degradation, including coastal abrasion, ecosystem damage, and the death of natural resources in the waters. Moreover, the population decline can also be caused by intensive fishing by fishermen. Horseshoe crabs live at the bottom of calm coastal waters and river estuaries with sandy and muddy bottoms [4], [5]. Their spread in Indonesia includes the East Coast of North Sumatra, West Sumatra, Kalimantan, North Sulawesi, and the North Coast of Java. One of the waters that have sandy and muddy bottoms is Sedati Waters. This coastal area has the potential of marine resources in capture fisheries and pond fisheries [6], [7].

Although horseshoe crabs in Sedati waters are not specific to fishermen's catch, it is suspected that their population and size keep decreasing. The roots of the problem are in the form of food availability and environmental factors [8], [9]. Thus, this study will examine the correlation between the environmental factors and the population of horseshoe crabs (*Tachypleus gigas*) in Sedati waters, Sidoarjo, East Java. The environmental factors include current, temperature, transparency, ammonia, degree of acidity (pH), dissolved oxygen (DO), salinity, and organic matter [10], [11].

II. Material and Method

A. Methodology

This research was conducted from October to December 2019. Sampling was carried out in Sedati waters, Sidoarjo District, East Java. The analysis of the population density of the horseshoe crabs was carried out at the Laboratory of Anatomy and Aquaculture, Faculty of Fisheries and Marine Affairs, Airlangga University, Surabaya. The analysis of seawater samples was carried out at the Laboratory of the Industrial Research and Standardization Agency (BARISTAND) Surabaya. The analysis of sediment texture was carried out at the Laboratory of Soil Mechanics, Faculty of Civil Engineering and Planning, Sepuluh Nopember Institute of Technology, Surabaya. Lastly, the analysis of organic matter was carried out at the Laboratory of Nutrition, Department of Health Nutrition, Faculty of Public Health, Airlangga University, Surabaya.

The research equipment used included a GPS, boat, dredget net, Ekman dredge, refractometer, Secchi disk, DO meter, pH meter, thermometer, plankton net, plastic clip, water sampler, and coolbox. The research materials used during the study included samples of horseshoe crabs, water, and bottom sediments of Sedati waters, Sidoarjo District.

B. Time and Location of Sampling

Sampling in Sedati waters was carried out once a month from October to December 2019. The sampling location was determined using the purposive sampling method. Sampling consisted of two zones, with each zone having three stations. The determination of the sampling was based on the prior preliminary research by taking samples at several points which were suspected to be the habitats of horseshoe crabs. After obtaining the appropriate points, with the help of GPS (Global Positioning System), the points were marked so that the positions did not change during the sampling time. The coordinates of the sampling location for the sampling location map can be seen in Figure 1.

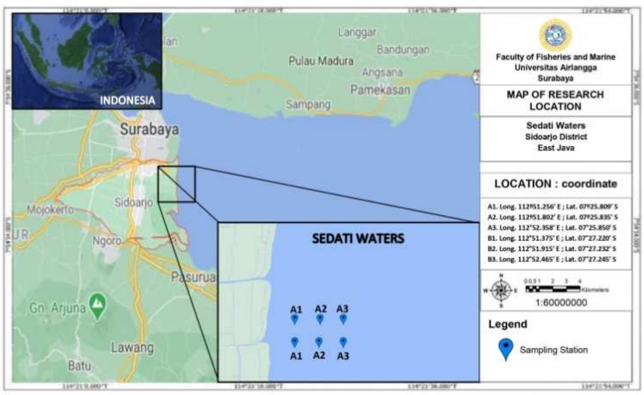


Fig. 1 Map of sampling locations

C. Sampling and Handling

A sampling of horseshoe crabs and macrofauna was carried out using a dredged net that was pulled 200 meters away. Meanwhile, the collections of sediments, benthos, and microfauna at the bottom waters were carried out using an Ekman dredge at the same points as the horseshoe crab sampling. Moreover, the sampling of plankton was carried out using a plankton net. Afterward, each sample was labeled per point of sampling, and then the samples were stored in a coolbox that had been given ice cubes.

D. Environmental Parameter Measurement

The measurement of temperature was using a thermometer, the measurement of dissolved oxygen (DO) was done using a DO meter, the measurement of salinity was done using a refractometer, the measurement of PH was done using a pH meter, and the measurement of transparency was done using a Secchi disc. Moreover, the measurement of ammonia was done by taking water samples, which afterward were put in a labeled 1.5-liter sampler bottle to be later stored in a coolbox that had been given ice cubes. Following this, the water samples were taken to the Laboratory of the Industrial Research and Standardization Agency (BARISTAND) Surabaya. Meanwhile, organic matter measurement was carried out at the Laboratory of Nutrition, Department of Health Nutrition, Faculty of Public Health, Airlangga University, Surabaya.

E. Analysis of the Population Density of Horseshoe Crabs

Density is a measure of the size of the population in units of space or volume. In general, the size of the population is described by the number of individuals. Calculating the population density of the horseshoe crabs was done using the formula formulated by [12].

F. Liniear Regression Analysis

Regression analysis was used to determine the correlation between the density of horseshoe crabs (*Tachypleus gigas*) and the environmental parameters. According to Sun *et al.* [13], linear equations can explain regression analysis.

G. Simple Correlation Analysis

Correlation analysis is an analysis used to measure the strength of the correlation between two variables. The strength of the correlation between the two variables might indicate whether the correlation is strong, weak, or not strong and whether the form of the correlation is a positive linear or negative linear correlation [14]. The correlation coefficient formula, according to Müller *et al.* [15] and the criteria for the degree of relationship or the correlation coefficient (R) according to Serrà *et al.* [16].

III. Results and Discussion

A. Population Density of Horseshoe Crabs

The results of data analysis on the average population density of horseshoe crabs (*Tachypleus gigas*) in Sedati waters during the study from October to December are presented in Table 1. Based on the study results, it is found that the average density of horseshoe crabs in Sedati waters (Table 1) in October was 0.08 ind/m2, in November was 0.05 ind / m2, and in December was 0.05 ind/m2. This result is in accordance with Xie *et al.* [21] statement that the amount of horseshoe crab distribution is influenced by several factors, including uniform environmental conditions, eating habits, and the ability to tolerate the availability of environmental resources.

TABLE I
THE RESULTS OF THE ANALYSIS OF THE AVERAGE POPULATION DENSITY DURING THE STUDY

Moon	Number of Individuals	The Average Horseshoe crab Population (ind/m^2)
October	16	0.08 ind/m^2
November	11	0.05 ind/m^2
December	11	0.05 ind/m^2

The number of horseshoe crabs in the B zone in October, November, and December was higher than in the A zone (Figure 2). This high number of horseshoe crabs in the B zone is due to the condition of the waters in the B zone, which is an open sea, having more supportive conditions in terms of water quality and nutrients compared to A zone, which is closer to the estuary, having a higher possibility to be polluted by human activities. Research by Meilana *et al.* [17] and Tanacredi *et al.* [18] regarding the distribution of horseshoe crabs in Balikpapan waters found that the number of horseshoe crabs in the open sea was 12 individuals, whose results were higher than the number of horseshoe crabs in the water near the estuary of only four individuals.

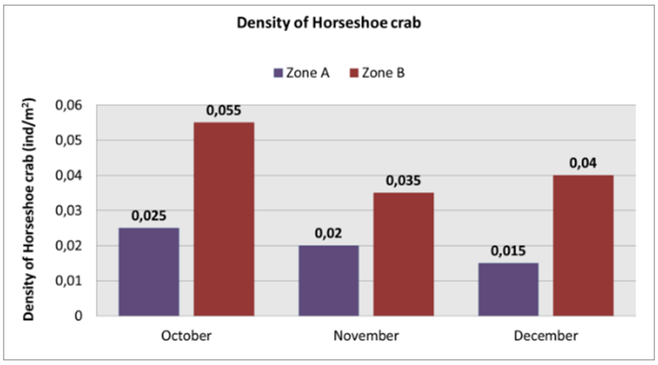


Fig. 2 Graph of the population density of horseshoe crabs

The relationship between the population density of horseshoe crabs and the temperature parameter has an R-value of 0.16, which is classified as having a very weak correlation and an R2 value of 0.026, which means that the temperature value affects the horseshoe crab population by 2.6%. The temperature value does not influence the population because the horseshoe crabs have a relatively wide temperature susceptibility to live in a range of low and high temperatures.

According to research conducted by Rubiyanto [19], the tolerance range of horseshoe crabs to temperature ranges from 1.1 - 40 ° C, but at a low-temperature range of 9 °C, the horseshoe crabs tend to be inactive compared to at high temperatures [20]. The relationship between the population density of horseshoe crabs and the transparency parameter has an R-value of 0.61, which is classified as having a strong correlation and an R2 value of 0.372, which means that the transparency value affects the horseshoe crab population by 37% (Figure 3).

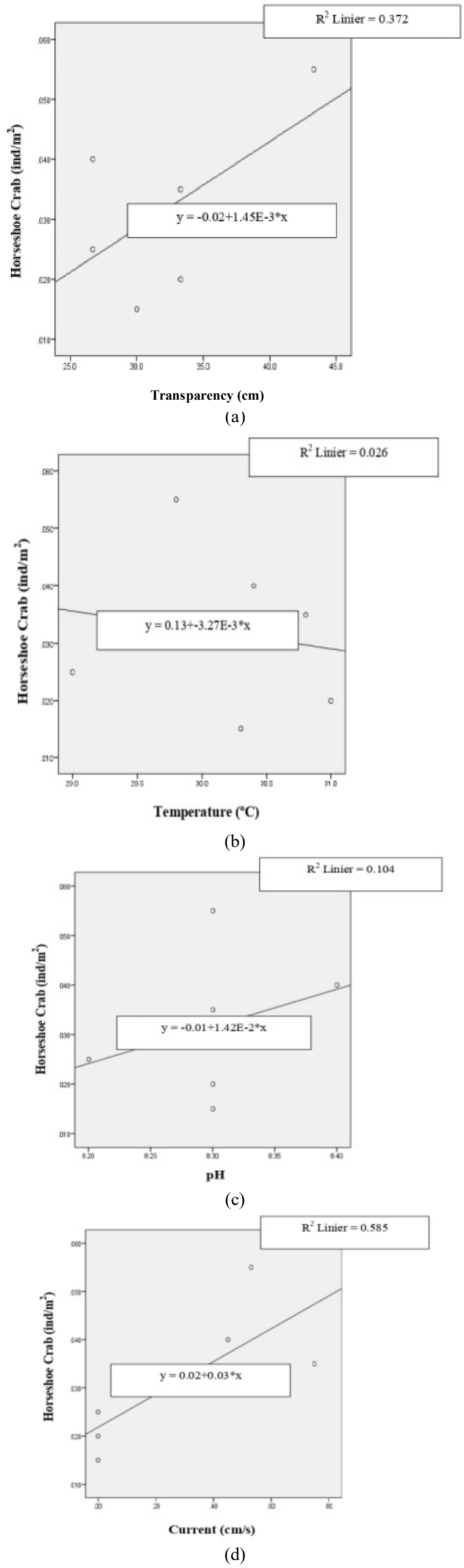


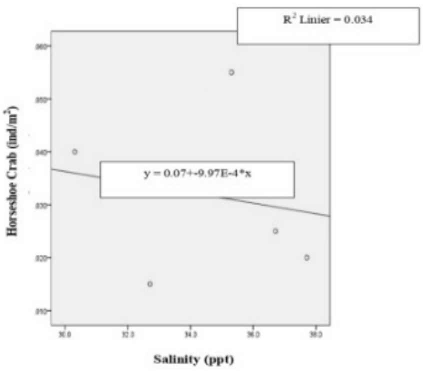
Fig. 3 Linear regression graph of the relationship between horseshoe crab population density and environmental factors, a. transparency; b. temperature; c. pH; and d. Current.

The transparency value in the waters influences the density of the horseshoe crabs. The higher the transparency of the waters, the higher the level of oxygen, followed by an increase in the productivity in the waters [8], [21]. In Sedati waters, many horseshoe crabs are found at a transparency level of 43.3 cm. This result is supported by the research of [19] regarding the study of the horseshoe crab population in Tungkal waters, where horseshoe crabs were found in the transparency range of 30-46 cm.

The relationship between the population density of horseshoe crabs and the current parameter has an R-value (correlation coefficient) of 0.76, which means that it has a very strong correlation. Meanwhile, the value of R2 (coefficient of determination) of current is 0.58, which means that the current has an effect on the horseshoe crab population of 58% (Figure 3). The highest density of horseshoe crabs in Sedati waters in October is in the B zone, which has a current value of 0.53 c/s. This value indicates that Sedati waters are included in the category of calm waters. A very strong correlation between current and the density of horseshoe crabs is because these animals are found mostly in calm waters. This is consistent with Aini *et al.* [3] and Wardiatno *et al.* [4], which states that horseshoe crabs are mostly found in calm waters. If the current in the waters is heavy, it can make it difficult for these organisms to adapt [11], [22].

The relationship of the population density of the horseshoe crabs in the waters and pH parameter has an R-value of 0.32, which is classified as having a moderate correlation. Meanwhile, the R2 value is 0.104, which means that the pH value (X) has an effect on the horseshoe crab population of 10% (Figure 3). This moderate correlation can be seen in Sedati waters, where the B zone has a pH value of 8.3 and has the most catch in October. This is because the pH value of Sedati waters is still in the normal range and is still feasible for the survival of horseshoe crabs.

The relationship between the population density of horseshoe crabs and the salinity parameter has an R-value of 0.18, which means that the correlation is very weak, and an R2 value of 0.034, which means that the salinity value has an influence on the horseshoe crab population of 3.4%. The salinity value has a very weak correlation with the density of horseshoe crabs. Salinity is related to the balance of body fluids in organisms, but in horseshoe crabs it does not really have an effect on their density because they belong to hypersaline species, so they can live both in high and low salinity.



(a)

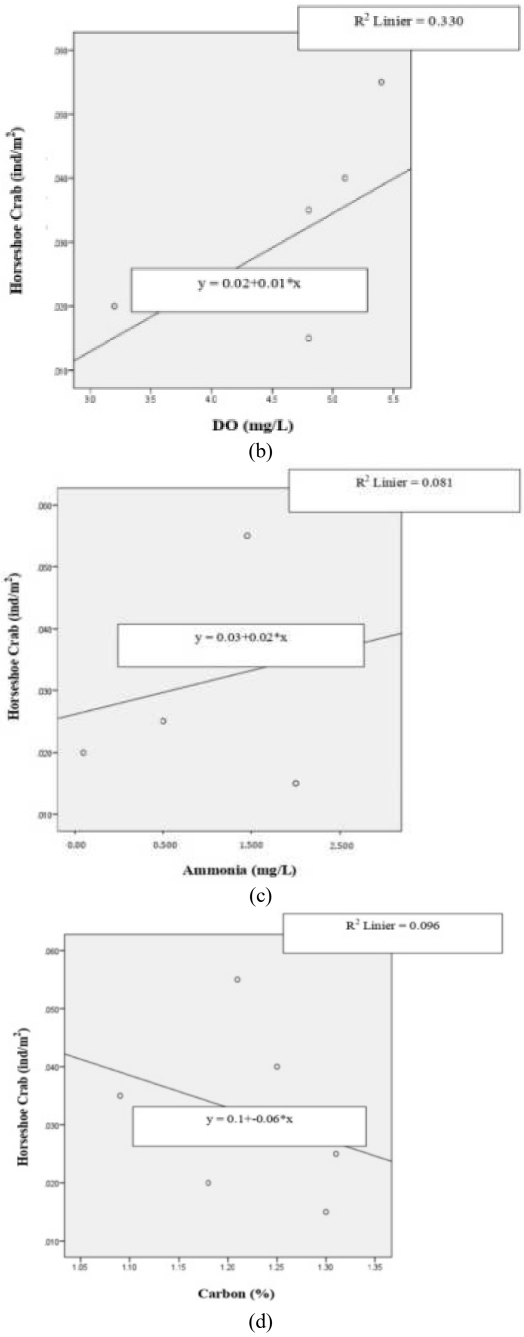


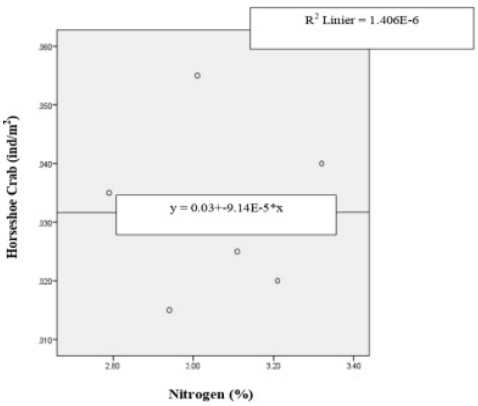
Fig. 4 Linear regression graph of the relationship between horseshoe crab population density and environmental factors, a. salinity; b. DO; c. ammonia; and d. carbon.

The relationship between the density of horseshoe crabs and dissolved oxygen (DO) parameter has an R value of 0.57, which is classified as having a strong correlation and an R2 value of 0.33, which means that the DO value has an effect on the horseshoe crab population of 33% (Figure 4). The better the DO levels in the waters, the higher the population of horseshoe crabs, meaning that if DO level decreases, the population of horseshoe crabs will also decrease [23].

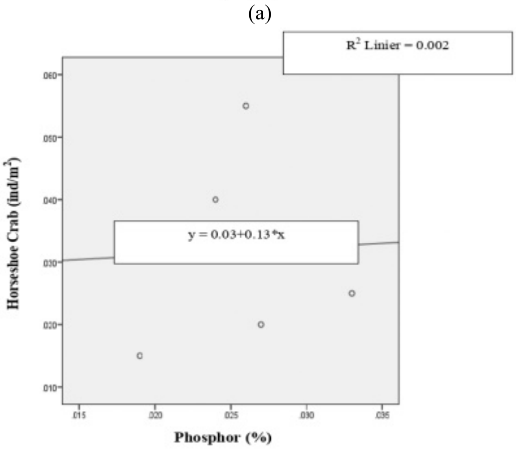
The relationship between the population density of horseshoe crabs and the ammonia parameter has an R-value of 0.28, which is classified as a moderate correlation, and an R2 value of 0.081, which means that the ammonia value has an effect on the horseshoe crab population of 8.1%. Sedati waters have an average concentration of ammonia for each zone which is still in accordance with the standard threshold stated in the Decree of the State Minister of the Environment No.51 of 2004, which is less than 0.3 mg / L. The population density in B zone is relatively large because the horseshoe crabs are still tolerant of the existing range of ammonia concentrations, but according to Velayudham *et al.* [11], Zhang *et al.* [9], and Xie *et al.* [21] that an increase in ammonia value can cause a decrease in the organisms' immune system and create stress that threatens the organisms' survival.

The relationship between the population density of horseshoe crabs and the carbon parameter has an R-value of 0.31, which is classified as a moderate correlation, and an R2 value of 0.096, which means that the carbon value has an effect on the horseshoe crab population of 9.6%. Based on the study results, the high or low value of carbon does not directly affect the horseshoe crab population because the carbon element plays a greater role in phytoplankton biomass [24], [25].

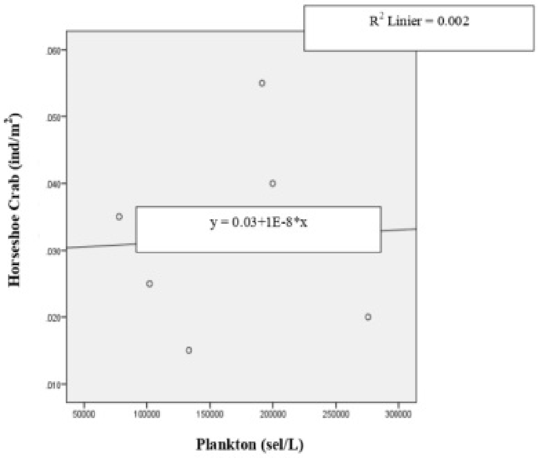
The relationship between horseshoe crab density and nitrogen parameter has an R-value of 0.001, classified as having no correlation and an R2 value of 0, which means that the nitrogen value does not affect the horseshoe crab population because the percentage is 0% (Figure 5). Nitrogen content on horseshoe crab density is classified as not correlate because nitrogen is used more by the biota of the P*olychaeta* class, not by the *Arthropod* class. According to Sari *et al.* [26], nitrogen in the waters is mostly used as a food source for *Polychaeta* class biota and other benthos. Futuyma [12] also states that horseshoe crabs can eat soft invertebrates found at the bottom water.



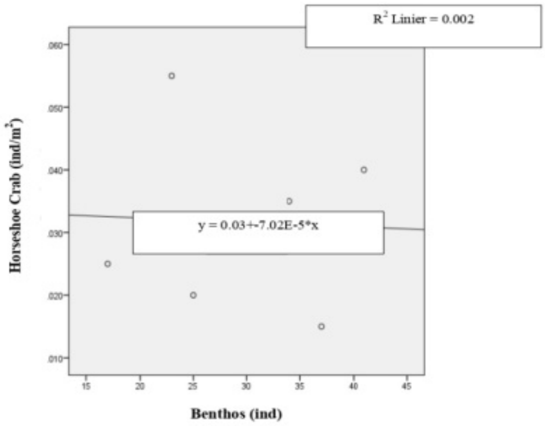
(a)



(b)



(c)



(d)

Fig. 5 Linear regression graph of the relationship between horseshoe crab population density and environmental factors, a. nitrogen; b. phosphor; c. plankton; and d. benthos

The relationship between the population density of horseshoe crabs and the phosphate parameter has an R-value of 0.04, which is classified as having no correlation and an R2 value of 0.002, which means that the phosphate value has an effect on the horseshoe crab population of 0.2% (Figure 5). The phosphate presence does not directly affect the horseshoe crab population because algae more widely use phosphate as an essential element in the waters [26]. Fertile waters can support an increase in the population of an organism, one of which is a horseshoe crab. In fact, the role of phosphate in waters is an element that is essential for the growth and survival of organisms[22].

The relationship between the population density of horseshoe crabs and biological parameters, including plankton density, has an R-value of 0.05, which is classified as not correlate, and R2 of 0.002, which means that the plankton density value affects the horseshoe crab population of 0.2% (Figure 5). The relationship between the population density of horseshoe crabs and plankton density shows no correlation because basically, the plankton in the waters plays a role as a determinant of the fertility of the water quality. According to Sari *et al.* [27], the presence of plankton has a very important role in waters, and it can be used to identify the fertility of waters.

The relationship between the population density of horseshoe crabs and benthos density has an R-value of 0.044, which is classified as having no correlation, and R2 of 0.002, which means that the benthos density value has an effect on the horseshoe crab population of 0.2% (Figure 6). The density population of horseshoe crabs and the density of benthos are classified as not correlated because benthos and horseshoe crabs act as detritus in the food chain in the waters. According to Kusumawati and Huang [28], detritus acts as a decomposition, making it easier to decompose organic matter into inorganic matter, which is a nutrient for producers in the waters.

The relationship between the population density of horseshoe crabs and macrofauna density has an R-value of 0.055, which is classified as not correlate, and R2 of 0.002, which means that the macrofauna density value affects the horseshoe crab population of 0.2% (Figure 6). The correlation of horseshoe crab density with macrofauna density does not significantly affect the macrofauna found in Sedati waters is a type of fish.

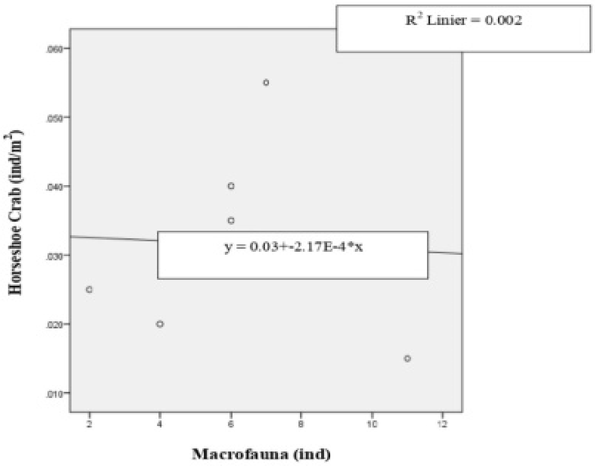


Fig. 6 Linear regression graph of the relationship between the population density of horseshoe crabs and an environmental factor, macrofauna

A. Physical and Chemical Parameters

A physical parameter in the form of the current value in the A zone in October was 0 cm/s, while the B zone was greater, namely 0.53 cm/s. The high value of currents in the B zone can be due to its location on the open sea, yet Sedati waters can still be categorized as calm waters. According to Arbi *et al.* [25], the difference in currents every month is influenced by the position of the waters, current patterns, water mass, tides, and wind movements.

The temperature obtained during the observation in October in A zone was 29˚C, and in the B zone, it was 29.8 C. Fluctuations in the water temperature are influenced by several factors, including solar radiation, geographical location of waters, current circulation, ocean depth, wind, and season. Meanwhile, the transparency value obtained during research in Sedati waters in A zone in October was 26.7 cm, while the B zone had the highest value at 43.3 cm. The observation results on transparency in Sedati waters show relatively different values. The relatively low transparency of Sedati waters can be caused by substrates/mud at the bottom water. According to Wang and Zhang [29], turbidity can describe the lack of transparency in waters caused by colloidal and suspended materials such as mud, organic and inorganic materials, and aquatic microorganisms.

Salinity in A zone had a value of 36.7 ppt, and in B zone, the salinity level in October had the highest value of 35.3 ppt. In October, the high salinity level in Sedati waters is due to the relatively low rainfall, so there is not much fresh water that is carried from the river to the sea. Fluctuating salinity levels are influenced by several factors such as water circulation patterns, evaporation, rainfall, and river flow [30].

The pH values obtained during observations in A zone and B were relatively the same. In October, the pH condition was more suitable in the B zone as a habitat for horseshoe crabs. This is indicated by the value of horseshoe crab density which was higher than the value in A zone. According to Sutomo [31], the ideal pH value of marine waters for organisms is between 7 - 8.5. Changes in pH above normal will increase ammonia, which is toxic to aquatic organisms [32].

The DO level obtained during observation in A zone in October was 5.1 mg / L, while in B zone, the DO level had the highest value of 5.4 mg / L. Dissolved oxygen is an environmental factor that is very important in waters, especially in the respiration process of most aquatic organisms. According to Wang and Zhang [29], oxygen levels in the waters are greatly influenced by the increase in organic materials that enter the waters.

The ammonia level obtained during the observation in October in the A zone was 0.2 mg/L. In comparison, the ammonia level in zone B was 0.39 mg/L. Based on the ammonia quality standard for marine biota stated in the Decree of the State Minister for the Environment No.51 of 2004. In October and November, the ammonia level is still under the threshold standard. The level is less than 0.3 mg/L, leading to a relatively high population of horseshoe crabs in those two months.

B. Sediments at the Bottom Water

The sediment composition in Sedati waters consists of three types of substrates, namely gravel, sand, and mud. The value of the mud substrate content was the highest of the value of other types of substrates of 86.47% in the A zone and of 81.59% in the B zone. The high composition of the mud substrate is due to the sediment material's size distribution, which is influenced by several factors such as distance from the coastline, distance from rivers, material sources, topography, and sediment transport mechanisms [33].

In October, the carbon content in zone A was 1.31%, while the highest density of horseshoe crabs was found in zone B in October, with a carbon content of 1.21%. The difference in nitrogen content in the waters can be due to a high number of primary sources of organic matter, which can come from organic tissues such as fallen leaves and organisms associated with plants and degraded in sediments. According to Yuan *et al.* [14] and Arbi *et al.* [25], the carbon element is used by aquatic organisms in the food chain cycle of marine ecosystems as a source of nutrition. Low carbon levels are caused by a high sedimentation process and its utilization by aquatic organisms [33].

In October, the nitrogen content in zone A was 3.11%, while the highest horseshoe crab density was in Zone B, with a nitrogen content of 3.01%. According to Arbi *et al.* [25], nitrogen levels can determine the level of water fertility. The level of nitrogen content in oligotrophic waters is 0-1 mg/L, in mesotrophic waters is 1-5 mg/L, and in eutrophic waters is 5 - 50 mg / L. Nitrogen in the waters is in the form of nitrate (NO3), nitrite (NO2), and ammonia (NH4). The nitrogen is then absorbed by aquatic biota for further use, and this causes the nitrogen to have been broken down first so that only a small amount is deposited [34].

The phosphate content in the A zone in October was 0.033%, while the highest crop density was in the B zone in October, with the highest phosphate content at 0.026%. This phosphate level still belongs to the category of fertile waters and is suitable for marine life. According to Imchen *et al.* [23], the standard quality of phosphate concentration suitable for marine life is 0.015%, so Sedati waters are classified as fertile waters. Phosphate levels tend to increase when rainfall decreases and vice versa [35]–[37]

IV. Conclusion

The results show that the average density of horseshoe crabs in October was 0.08 ind/ m2, in November was 0.05 ind/m2, and in December was 0.05 ind/m2. The correlation between the horseshoe crabs and the highest water quality parameters is noted in a current of 58%, transparency of 37%, and DO of 33%. Based on the results of this study, the environmental conditions in Sedati waters are supported by several water quality parameters which are categorized as acceptable, while the organic matter is included in the category that does not exceed the safe threshold. In addition, the sediment conditions at the bottom water are mostly dominated by mud content. Moreover, based on the results of correlation-regression, the environmental factors have a strong correlation on the horseshoe population in Sedati waters, including transparency, currents, and DO, while parameters of pH, ammonia, carbon, and microfauna have a quite influential effect on the population of horseshoe crabs.

Acknowledgment

The authors are grateful to the Faculty of Fisheries and Marine, Universitas Airlangga, for providing financial assistance (RKAT) and tools in research.

References

[1] J. C. Lamsdell and S. C. McKenzie, "Tachypleus syriacus (Woodward)—a sexually dimorphic Cretaceous crown limulid reveals underestimated horseshoe crab divergence times," *Org. Divers. Evol.*, vol. 15, no. 4, pp. 681–693, 2015, doi: 10.1007/s13127-015-0229-3.

[2] V. Chen, C.-P., Laurie, K., Yang, M., Seino, S., Mohamad, F., Cheung, S.G., Shin, N., Hsieh, H., John, A., Shin, P., Do, "Tachypleus tridentatus , Tri-spine Horseshoe Crab," vol. 8235, p. e.T21309A133299524, 2019.

[3] N. K. Aini, A. Mashar, H. H. Madduppa, and Y. Wardiatno, "Keragaman genetik mimi (Carcinoscorpius rotundicauda dan Tachypleus gigas) di perairan Demak, Madura dan Balikpapan berdasarkan penanda Random Amplified Polymorphic DNA," *J. Pengelolaan Sumberd. Alam dan Lingkung. (Journal Nat. Resour. Environ. Manag.*, vol. 10, no. 1, pp. 124–137, 2020, doi: 10.29244/jpsl.10.1.124-137.

[4] N. A. Wardiatno, Y., Kurnia, R., Butet, "Taxonomic Certainty and Distribution of Tri-Spine Horseshoe," *J. Ilmu dan Teknol. Kelaut. Trop.*, vol. 10, no. 3, 2018.

[5] J. T. Tanacredi, M. L. Botton, and D. R. Smith, "Biology and conservation of horseshoe crabs," *Biol. Conserv. Horseshoe Crabs*, pp. 1–662, 2009, doi: 10.1007/978-0-387-89959-6.

[6] I. G. A. P. Eryani, I. W. Runa, and M. W. Jayantari, "Water potential management and arrangement of river estuary area for the mitigation of the climate change in Bali," *Int. J. Adv. Sci. Eng. Inf. Technol.*, vol. 9, no. 3, pp. 849–854, 2019, doi: 10.18517/ijaseit.9.3.8224.

[7] G. Gumbira and B. Harsanto, "Decision support system for an eco-friendly integrated coastal zone management (ICZM) in Indonesia," *Int. J. Adv. Sci. Eng. Inf. Technol.*, vol. 9, no. 4, pp. 1177–1182, 2019, doi: 10.18517/ijaseit.9.4.9484.

[8] L. M. Hernández-Terrones, K. A. Null, D. Ortega-Camacho, and A. Paytan, "Water quality assessment in the Mexican Caribbean: Impacts on the coastal ecosystem," *Cont. Shelf Res.*, vol. 102, pp. 62–72, 2015, doi: 10.1016/j.csr.2015.04.015.

[9] L. Zhang, L. Xiong, J. Li, and X. Huang, "Long-term changes of nutrients and biocenoses indicating the anthropogenic influences on ecosystem in Jiaozhou Bay and Daya Bay, China," *Mar. Pollut. Bull.*, vol. 168, no. April, p. 112406, 2021, doi: 10.1016/j.marpolbul.2021.112406.

[10] A. Kaleli, M. S. Kulikovskiy, and C. N. Solak, "Some New Records for Marine Diatom Flora of Turkey from Akliman, Sinop (Black Sea)," *Turkish J. Fish. Aquat. Sci.*, vol. 17, pp. 1387–1395, 2017, doi: 10.4194/1303-2712-v17.

[11] N. Velayudham, D. D. V, and A. A. C, "Macrobenthic diversity and community structure at Cochin Port, an estuarine habitat along the southwest coast of India," *Reg. Stud. Mar. Sci.*, vol. 34, p. 101075, 2020, doi: 10.1016/j.rsma.2020.101075.

[12] D. J. Futuyma, *Ecology. The Experimental Analysis of Distribution and Abundance. Charles J. Krebs* , vol. 48, no. 1, Part 1. 1973.

[13] T. Sun, J. Zhan, F. Li, C. Ji, and H. Wu, "Environmentally relevant concentrations of microplastics influence the locomotor activity of aquatic biota," *J. Hazard. Mater.*, vol. 414, no. January, p. 125581, 2021, doi: 10.1016/j.jhazmat.2021.125581.

[14] X. Yuan, Q. Yang, X. Luo, F. Yu, F. Liu, J. Li, and Z. Wang, "Distribution of grain size and organic elemental composition of the surficial sediments in Lingding Bay in the Pearl River Delta, China: A record of recent human activity," Ocean & Coastal Management, vol. 178, p. 104849, Aug. 2019, doi: 10.1016/j.ocecoaman.2019.104849.

[15] F. Müller, S. Bicking, K. Ahrendt, D. Kinh Bac, I. Blindow, C. Fürst, P. Haase, M. Kruse, T. Kruse, L. Ma, M. Perennes, I. Ruljevic, G. Schernewski, C.-G. Schimming, A. Schneiders, H. Schubert, noteJohanna Schumacher, U. Tappeiner, P. Wangai, W. Windhorst, and J. Zeleny, "Assessing ecosystem service potentials to evaluate terrestrial, coastal and marine ecosystem types in Northern Germany – An expert-based matrix approach," Ecological Indicators, vol. 112, p. 106116, May 2020, doi: 10.1016/j.ecolind.2020.106116.

[16] A. Serrà, Y. Zhang, B. Sepúlveda, E. Gómez, J. Nogués, J. Michler, and L. Philippe, "Highly reduced ecotoxicity of ZnO-based micro/nanostructures on aquatic biota: Influence of architecture, chemical composition, fixation, and photocatalytic efficiency," Water Research, vol. 169, p. 115210, Feb. 2020, doi: 10.1016/j.watres.2019.115210.

[17] L. Meilana, Y. Wardiatno, N. A. Butet, and M. Krisanti, "Karakter Morfologi Dan Identifikasi Molekuler Dengan Marka Gen CO1 pada Mimi (Tachypleus gigas) di Perairan Utara Pulau Jawa," *J. Ilmu dan Teknol. Kelaut. Trop.*, vol. 8, no. 1, pp. 145–148, 2016.

[18] J. T. Tanacredi, M. L. Botton, and D. R. Smith, *Preface*. 2009.

[19] E. Rubiyanto, "Studi populasi mimi (Xiphosura) di perairan Kuala Tungkal, Kabupaten Tanjung Jabung Barat, Jambi." Tesis. Universitas Indonesia. 66hlm, 2012.

[20] P. Jiang, H. Xia, Z. He, and Z. Wang, "Design of a water environment monitoring system based on wireless sensor networks," *Sensors*, vol. 9, no. 8, pp. 6411–6434, 2009, doi: 10.3390/s90806411.

[21] Z. Xie, J. Zhang, K. Cai, Z. Xu, D. Wu, and B. Wang, "Temporal and spatial distribution of macrobenthos communities and their responses to environmental factors in Lake Taihu," *Shengtai Xuebao/ Acta Ecol. Sin.*, vol. 36, no. 1, pp. 16–22, 2016, doi: 10.1016/j.chnaes.2015.12.005.

[22] N. Z. Al Diana, L. A. Sari, S. Arsad, K. T. Pursetyo, and Y. Cahyoko, "Monitoring of Phytoplankton Abundance and Chlorophyll-a Content in the Estuary of Banjar Kemuning River, Sidoarjo Regency, East Java," *J. Ecol. Eng.*, vol. 22, no. 1, pp. 29–35, 2020, doi: 10.12911/22998993/128877.

[23] T. Imchen, W. Ezaz, and S. S. Sawant, "Potential contribution to the nutrient pool due to the decomposition of Eichhornia crassipes under different salinity in an aquatic ecosystem—A laboratory study," *Reg. Stud. Mar. Sci.*, vol. 35, p. 101222, 2020, doi: 10.1016/j.rsma.2020.101222.

[24] J. L. Li, X. Zhai, and L. Du, "Photosensitized formation of sulfate and volatile sulfur gases from dissolved organic sulfur: Roles of pH, dissolved oxygen, and salinity," *Sci. Total Environ.*, vol. 786, p. 147449, 2021, doi: 10.1016/j.scitotenv.2021.147449.

[25] I. Arbi, S. Liu, J. Zhang, Y. Wu, and X. Huang, "Detection of terrigenous and marine organic matter flow into a eutrophic semi-

enclosed bay by δ13C and δ15N of intertidal macrobenthos and basal food sources," *Sci. Total Environ.*, vol. 613–614, pp. 847–860, 2018, doi: 10.1016/j.scitotenv.2017.09.143.

[26] L. A. Sari, W. H. Satyantini, A. Manan, K. T. Pursetyo, and N. N. Dewi, "The identification of plankton tropical status in the Wonokromo, Dadapan and Juanda extreme water estuary," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 137, no. 1, pp. 0–6, 2018, doi: 10.1088/1755-1315/137/1/012029.

[27] L. A. Sari, P. D. W. Sari, D. D. Nindarwi, S. Arsad, and M. Affandi, "Harmful algae identification in bomo water environment, banyuwangi, east java, Indonesia," *Ecol. Environ. Conserv.*, vol. 25, pp. S26–S31, 2019.

[28] I. Kusumawati and H. W. Huang, "Key factors for successful management of marine protected areas: A comparison of stakeholders' perception of two MPAs in Weh island, Sabang, Aceh, Indonesia," *Mar. Policy*, vol. 51, pp. 465–475, 2015, doi: 10.1016/j.marpol.2014.09.029.

[29] J. Wang and Z. Zhang, "Phytoplankton, dissolved oxygen and nutrient patterns along a eutrophic river-estuary continuum: Observation and modeling," *J. Environ. Manage.*, vol. 261, no. March, p. 110233, 2020, doi: 10.1016/j.jenvman.2020.110233.

[30] F. M. Tsai, T. D. Bui, M. L. Tseng, M. K. Lim, and R. R. Tan, "Sustainable solid-waste management in coastal and marine tourism cities in Vietnam: A hierarchical-level approach," *Resour. Conserv. Recycl.*, vol. 168, no. October 2020, p. 105266, 2021, doi: 10.1016/j.resconrec.2020.105266.

[31] I. Sutomo, "Modification of character education into akhlaqeducation for the global community life - Indonesian Journal of Islam and Muslim Societies PDFijims.iainsalatiga.ac.id › article › download," *Indones. J. Islam Muslim Soc.*, vol. 4, no. 2, pp. 291–316, 2014.

[32] A. Sahri, P. L. K. Mustika, H. Y. Dewanto, and A. J. Murk, "A critical review of marine mammal governance and protection in Indonesia," *Mar. Policy*, vol. 117, p. 103893, 2020, doi: 10.1016/j.marpol.2020.103893.

[33] Y. Ma, A. Hu, C.-P. Yu, Q. Yan, X. Yan, Y. Wang, F. Deng, and H. Xiong, "Response of microbial communities to bioturbation by artificially introducing macrobenthos to mudflat sediments for in situ bioremediation in a typical semi-enclosed bay, southeast China," Marine Pollution Bulletin, vol. 94, no. 1–2, pp. 114–122, May 2015, doi: 10.1016/j.marpolbul.2015.03.003.

[34] C. N. Hewitt, A. R. MacKenzie, P. Di Carlo, C. F. Di Marco, J. R. Dorsey, M. Evans, D. Fowler, M. W. Gallagher, J. R. Hopkins, C. E. Jones, B. Langford, J. D. Lee, A. C. Lewis, S. F. Lim, J. McQuaid, P. Misztal, S. J. Moller, P. S. Monks, E. Nemitz, D. E. Oram, S. M. Owen, G. J. Phillips, T. A. M. Pugh, J. A. Pyle, C. E. Reeves, J. Ryder, J. Siong, U. Skiba, and D. J. Stewart, "Nitrogen management is essential to prevent tropical oil palm plantations from causing ground-level ozone pollution," Proceedings of the National Academy of Sciences, vol. 106, no. 44, pp. 18447–18451, Nov. 2009, doi: 10.1073/pnas.0907541106.

[35] J. Mathew, A. Singh, and A. Gopinath, "Nutrient concentrations and distribution of phytoplankton pigments in recently deposited sediments of a positive tropical estuary," *Mar. Pollut. Bull.*, vol. 168, no. May, p. 112454, 2021, doi: 10.1016/j.marpolbul.2021.112454.

[36] B. O. Isiuku and C. E. Enyoh, "Pollution and health risks assessment of nitrate and phosphate concentrations in water bodies in South Eastern, Nigeria," *Environ. Adv.*, vol. 2, no. October, p. 100018, 2020, doi: 10.1016/j.envadv.2020.100018.

[37] K. Vijayaraghavan and R. Balasubramanian, "Application of pinewood waste-derived biochar for the removal of nitrate and phosphate from single and binary solutions," *Chemosphere*, vol. 278, p. 130361, 2021, doi: 10.1016/j.chemosphere.2021.130361.