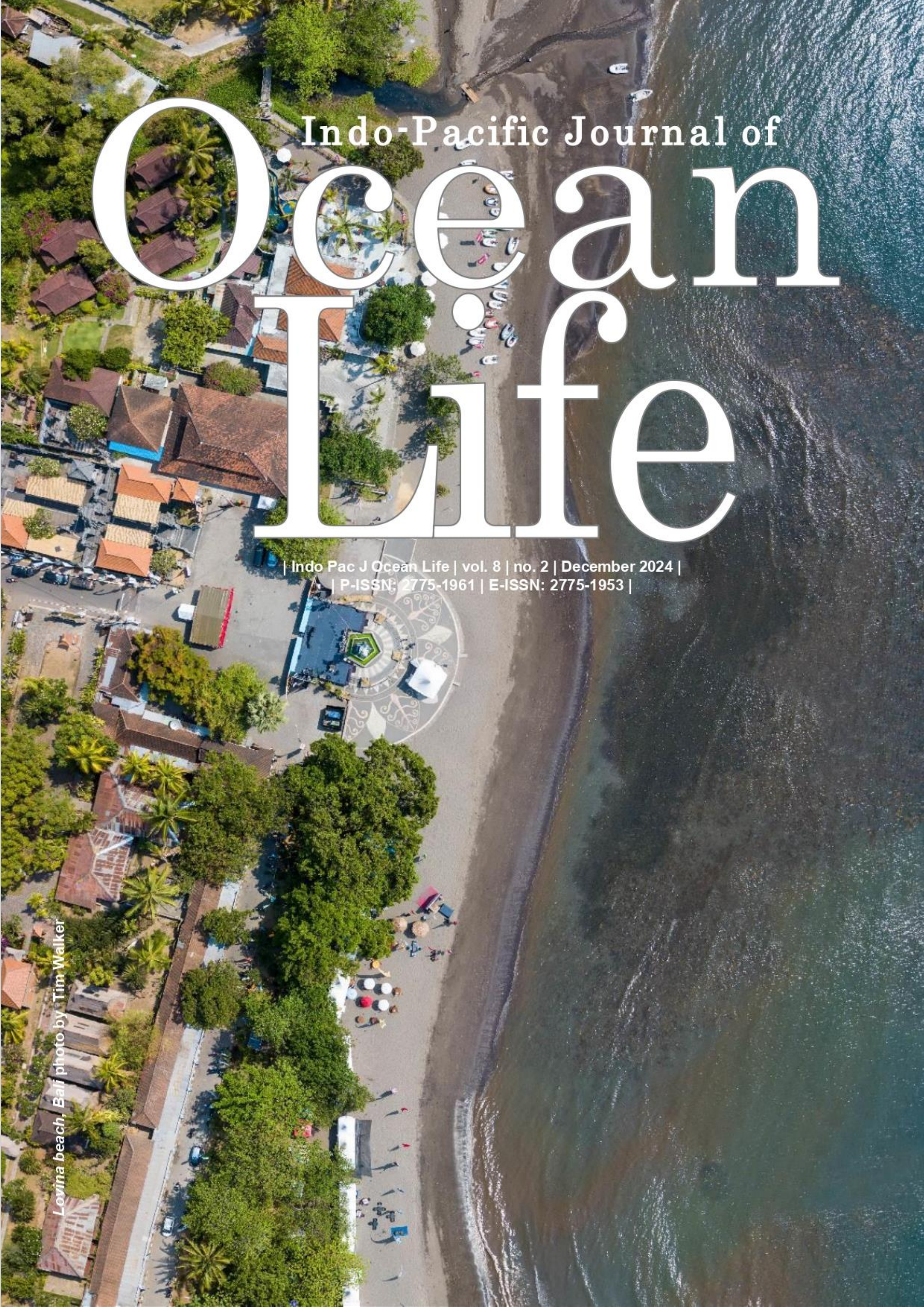
Indo-Pacific Journal of

Ocean Life

| Indo Pac J Ocean Life | vol. 8 | no. 2 | December 2024 |
| P-ISSN: 2775-1961 | E-ISSN: 2775-1953 |



Lovina beach, Bali photo by Tim Walker

Indo-Pacific Journal of
Ocean Life

| Indo Pac J Ocean Life | vol. 8 | no. 2 | December 2024 | P-ISSN: 2775-1961 | E-ISSN: 2775-1953 |

Published semiannually **PRINTED IN INDONESIA**

P-ISSN: 2775-1961
9 772775 196165

E-ISSN: 2775-1953
9 772775 195168

Indo-Pacific Journal of
Ocean Life

| Indo Pac J Ocean Life | vol. 8 | no. 2 | December 2024 |

ONLINE
http://smujo.id/ol

p-ISSN: 2775-1961; **e-ISSN:** 2775-1953

PUBLISHER
Smujo International

ASSOCIATION
Society for Indonesian Biodiversity

INSTITUTION
Universitas Papua, Manokwari, Indonesia

OFFICE ADDRESS
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Tel./fax.: +62-986-212156/211455, email: editors@smujo.id

PERIOD OF ISSUANCE
June, December

Society for Indonesian Biodiversity

Universitas Papua, Manokwari, Indonesia

Published by Smujo International for The Society for Indonesian Biodiversity and Universitas Papua Manokwari, Indonesia

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Abstract A concise abstract is required (about 200 words). The abstract should be informative and state briefly the aim of the research, the principal results and major conclusions. An abstract is often presented separately from the article, thus it must be able to stand alone (completely self-explanatory). References should not be cited, but if essential, then cite the author(s) and year(s). Abbreviations should be avoided, but if essential, they must be defined at their first mention. **Keywords** are about five words, covering scientific and local name (if any), research themes, and special methods used; and sorted from A to Z. **Abbreviations** (if any): All important abbreviations must be defined at their first mention there. **Running title** is about five words.

Introduction is about 600 words, covering the aims of the research and provide an adequate background, avoiding a detailed literature survey or a summary of the results. **Materials and Methods** should emphasize on the procedures and data analysis. **Results and Discussion** should be written as a series of connecting sentences, however, for a manuscript with long discussion should be divided into subtitles. Thorough discussion represents the causal effect mainly explains why and how the results of the research were taken place, and do not only re-express the mentioned results in the form of sentences. **Concluding** sentence should be given at the end of the discussion. **Acknowledgements** are expressed in a brief; all sources of institutional, private and corporate financial support for the work must be fully acknowledged, and any potential conflicts of interest are noted.

Figures and Tables of a maximum of three pages should be clearly presented. The title of a picture is written down below the picture, while the title of a table is written above the table. Colored figures can only be accepted if the information in the manuscript can lose without those images; the chart is preferred to use black and white images. The author could consign any picture or photo for the front cover, although it does not print in the manuscript. All images property of others should be mentioned the source. Author is suggested referring to Wikipedia for international boundaries and Google Earth for satellite imagery. If not specifically mentioned, it is assumed to refer to these sources. **There is no appendix**, all data or data analysis is incorporated into Results and Discussions. For broad data, it can be displayed on the website as a supplement.

References Preferably 80% of it comes from scientific journals published in the last 10 years. In the text, give the author names followed by the year of publication and arrange from oldest to newest and from A to Z; in citing an article written by two authors, both of them should be mentioned; however, for three and more authors only the first author is mentioned followed by et al. For example, Saharjo and Nurhayati (2006) or (Boonkerd 2003a, b, c; Sugiyarto 2004; El-Bana and Nijs 2005; Balagadde et al. 2008; Webb et al. 2008). Extent citation should be avoided, as shown with the word "cit." Reference to unpublished data and personal communication should not appear in the list but should be cited in the text only (e.g., Rifai MA 2007, pers. com. (personal communication); Setyawan AD 2007, unpublished data). In the reference list, the references should be listed in alphabetical order. Names of journals should be abbreviated. Always use the standard abbreviation of a journal's name according to the **ISSN List of Title Word Abbreviations** (www.issn.org/2-22661-LTWA-online.php). Please include DOI links for journal papers. The following examples are for guidance.

Journal:

Saharjo BH, Nurhayati AD. 2006. Domination and composition structure change at hemic peat natural regeneration following burning; a case study in Pelalawan, Riau Province. Biodiversitas 7: 154-158. DOI: 10.13057/biodiv/d070213.

The usage of "et al." in long author lists will also be accepted:

Smith J, Jones M Jr, Houghton L et al. 1999. Future of health insurance. N Engl J Med 965: 325-329. DOI: 10.10007/s002149800025.

Book:

Rai MK, Carpinella C. 2006. Naturally Occurring Bioactive Compounds. Elsevier, Amsterdam.

Chapter in the book:

Webb CO, Cannon CH, Davies SJ. 2008. Ecological organization, biogeography, and the phylogenetic structure of rainforest tree communities. In: Carson W, Schnitzer S (eds.). Tropical Forest Community Ecology. Wiley-Blackwell, New York.

Abstract:

Assaeed AM. 2007. Seed production and dispersal of *Rhazya stricta*. 50th annual symposium of the International Association for Vegetation Science, Swansea, UK, 23-27 July 2007.

Proceeding:

Alikodra HS. 2000. Biodiversity for development of local autonomous government. In: Setyawan AD, Sutarno (eds.). Toward Mount Lawu National Park; Proceeding of National Seminary and Workshop on Biodiversity Conservation to Protect and Save Germplasm in Java Island. Universitas Sebelas Maret, Surakarta, 17-20 July 2000. [Indonesian]

Thesis, Dissertation:

Sugiyarto. 2004. Soil Macro-invertebrates Diversity and Inter-Cropping Plants Productivity in Agroforestry System based on Sengon. [Dissertation]. Universitas Brawijaya, Malang. [Indonesian]

Information from the internet:

Balagadde FK, Song H, Ozaki J, Collins CH, Barnet M, Arnold FH, Quake SR, You L. 2008. A synthetic *Escherichia coli* predator-prey ecosystem. Mol Syst Biol 4: 187. DOI: 10.1038/msb.2008.24. www.molecularsystembiology.com.

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INDO PAC J OCEAN LIFE
Volume 8, Number 2, December 2024
Pages: 59-71

P-ISSN: 2775-1961
E-ISSN: 2775-1953
DOI: 10.13057/oceanlife/o080201

Diversity and composition of Crustacean and Mollusk in mangrove area of Sampang and Pamekasan Districts, Madura Island, Indonesia

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Manuscript received: 31 December 2023. Revision accepted: 18 October 2024.

Abstract. *Haqqi MRA, Sholichah DM, Ashila J, Reza AD, Indrawan M, Dadiono MS, Yap CK, Rahim KABA, Setyawan AD. 2024. Diversity and composition of Crustacean and Mollusk in mangrove area of Sampang and Pamekasan Districts, Madura Island, Indonesia. Indo Pac J Ocean Life 8: 59-71.* Mangrove ecosystem in Indonesia is the largest in the world and contains various biota with a great interest to study. An example of mangrove ecosystems can be found in Sampang and Pamekasan Districts, Madura Island which have a high potential for biodiversity, such as Crustacean and Mollusk. However, information regarding the diversity of Crustaceans and Mollusks in that territory is still very limited. Therefore, this research was conducted to assess the diversity of Crustaceans and Mollusks in the mangrove area of Sampang and Pamekasan Districts. The study was conducted in December 2023 with data collection located at four stations: (i) Taddan, Camplong Sub-district and (ii) Song-Osong Beach, Sampang Sub-district, both in Sampang District; (iii) Branta Tinggi and (iv) Raya Ambat Street both in Tlanakan Sub-district, Pamekasan District. Data on biotic and abiotic environmental parameters was collected and sampling of Crustacean and Mollusk was conducted using Visual Encounter Survey (VES) and direct catching. The results showed that mangrove ecosystem in Sampang and Pamekasan Districts had certain similarities, i.e. both were composed by vegetation of *Sonneratia alba*, *Avicennia marina*, *Sonneratia caseolaris*, and *Rhizophora mucronata*. The environmental parameters measurement showed that the study area location has warm temperatures, wet soil, neutral pH, and relatively low salinity compared to Madura Strait. There were 32 Crustacean species with the mostly found was *Balanus* sp. (barnacle), followed by *Clibanarius longitarsus* (common hermit crab). The number of Mollusks obtained was 24 species with the mostly found was *Pirenella alata* and *Pirenella cingulata*. Based on ecological indices calculation, Crustacean on study area location had moderate diversity, high species richness, high evenness or stable community, and indicates no dominant species. While the Mollusk on study area location had moderate diversity, moderate species richness, high evenness or stable community, and indicates no dominant species. Station 3 (Branta Tinggi) had the highest number of Crustacean species, diversity, species richness, and evenness, while Station 4 (Raya Ambat Street) had the highest number of Mollusk species, diversity, species richness, and evenness.

Keywords: Crustacean, diversity, environment, Mollusk, mangrove

INTRODUCTION

Indonesia is an archipelagic country located at the equator and is among mega biodiversity countries along with Brazil, Colombia, and Zaire due to its high diversity of flora and fauna (Supriatna 2008). As a country composed of chain of islands, Indonesia has one of the longest coastlines in the world, stretches for 95,181 km (Subagio 2013), which consist of various complex ecosystems of marine and terrestrial realms. One of the unique coastal ecosystem found In Indonesia is mangrove, extending over 5,000 km from east to west (Supriatna 2008). Mangrove forest in Indonesia contributes to 50% of the total area of mangrove forests in Asia and almost 30% of the world (Onrizal 2018), making it as the country with the largest extent of mangrove in the world. Mangrove forests can be found in the entire region of Indonesia, both in areas with wet and dry seasonal climates, with the largest area is in Papua (Kartawinata 2013).

Mangrove ecosystem is located on transitional zone between terrestrial and marine realms, and is flooded by sea water during high tide and exposed to the air during low tide. It is characterized by salt-tolerant vegetation with complex root systems (Soeprobowati et al. 2024). Mangrove tree live in the intertidal zone of coastal bays and can may grow toward land for hundreds of meters where the area is far from the influence of ocean tides (Swasta 2018). Mangrove ecosystem is composed by interacting biotic and abiotic components between marine and terrestrial ecosystems which form unique features including the presence of mangrove vegetation (Saptutyningsih 2023). Mangrove forests grow and develop in estuary area, making it become biodiversity hotspots that providing habitat as a nursery, spawning and feeding grounds for various aquatic and terrestrial biota such as birds, fishes, shrimps, and crabs (Rangkuti et al. 2017).

Mangrove ecosystem are good examples of complex habitats, since they are among the most diverse and productive habitat types in coastal areas. On mangrove ecosystem, marine benthic invertebrates become keystone organisms which play an important role to create mangrove ecosystem complexity due to their horizontal and vertical distributions (Hajializadeh et al. 2020). The presence and activity of those macrozoobenthic animal has an effect that can influence the interaction and life of other components in mangrove ecosystem. The ecological importance of this animal in mangrove ecosystem includes as decomposer organism, promoting carbon and nutrient recycle, source of mineral for nature, improve oxygen aeration, and provide natural food for another biota (Ginantra et al. 2023). Crustaceans have an important position within the aquatic ecosystems at various food web levels, including as predators, scavengers, or filter feeders (Knigge et al. 2021). Mollusks play a role as a food chain detritus feeder in the nutrient cycle because Mollusks are early decomposers that chop mangrove leaves into small parts before consumed by smaller organisms (Odum 1996; Baderan et al. 2019). Some species of Crustaceans and Mollusks are used as water quality bioindicators and have economic value for human consumption (Sianipar et al. 2022). A better understanding of mangrove invertebrate ecology, especially Crustaceans and Mollusks, will help promote mangrove ecosystem conservation (Setyadi et al. 2021).

Mangrove ecosystem also occurs in Sampang and Pamekasan Districts, Madura Island, Indonesia, where the mangrove forests are mostly located at the sea edges with silt and sand substrates (Suprakto 2005; Muhsoni et al. 2013). Mangroves in Sampang and Pamekasan Districts are located in the south coast of Madura Island and have a vital role for local communities. Local people usually harvest shrimp, snail, clam, crab, and several types of fish from those location for economic and livelihood household needs (Arkham et al. 2018; Islamy and Hasan 2020). Several research related to the diversity of Crustacea and Mollusk in Sampang District have been done by Adhani et al. (2018), Pratiwi and Muhsoni (2021), and Wijaya and Ambarwati (2021), while similar research in Pamekasan District were carried out by Rahmasari et al. (2015), Farid et al. (2023), Istifadah and Ibana (2023), Iwandani et al. (2023), Afnani and Rahayu (2024) and Kurniawan et al. (2024). However, those research were limited to studying several classes or genera with incomplete biodiversity data because the focus of their study is not on diversity. Therefore, this study was conducted to fill the research gap related to ecological data, including abundance, diversity, distribution, dominance, evenness, species richness, and morphological record from Crustacean and Mollusk that found in mangrove area of Sampang and Pamekasan Districts. The results of this study are expected to serve as baseline data for future monitoring and to be used as consideration in restoration, conservation, and development strategies of mangrove areas in Sampang and Pamekasan Districts.

MATERIALS AND METHODS

Study period and area

The study was conducted in December 2023 and located in the mangrove ecosystem in the districts of Sampang and Pamekasan, Madura Island, East Java Province, Indonesia. Data collection was conducted at four stations i.e.: (i) first station located in Taddan, Camplong Sub-district, Sampang District; (ii) second station located in Song-Osong Beach, Sampang Sub-district, Sampang District; (iii) third station located in Branta Tinggi, Tlanakan Sub-district, Pamekasan District; and (iv) fourth station located aside of Raya Ambat Street, Tlanakan Sub-district, Pamekasan District (Figure 1). These four locations were determined to represent mangrove areas with different kinds and characteristics of the two districts. Taddan and Song-Osong Beach, respectively represented dense and sparse mangrove vegetation in Sampang, while Branta Tinggi and Raya Ambat Street, respectively represented dense and sparse mangrove vegetation in Pamekasan.

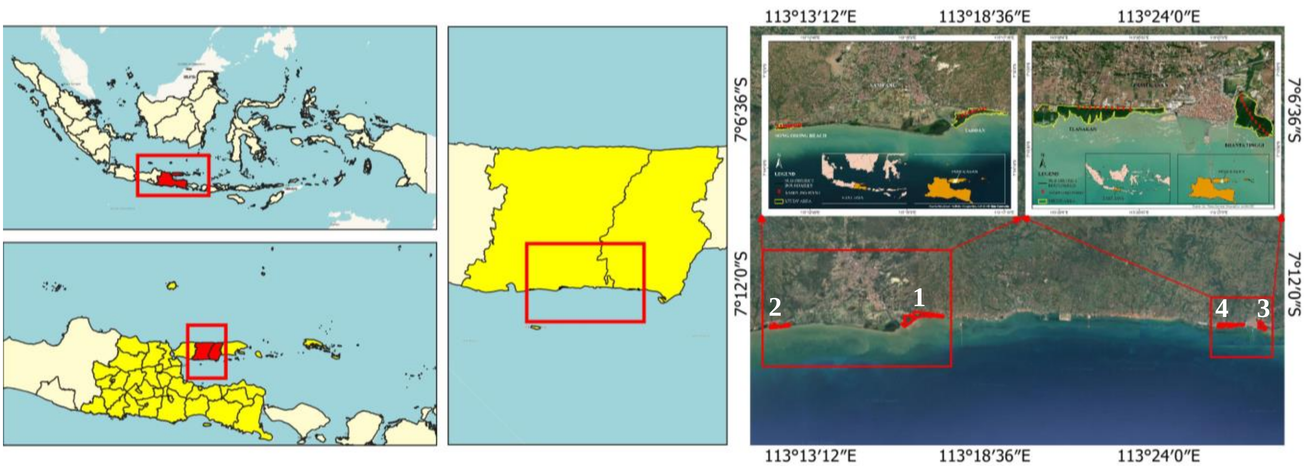

Figure 1. Map of study area showing four stations in Madura Island, East Java, Indonesia: Station 1 Taddan and Station 2 Song-Osong Beach in Sampang District; and Station 3 Branta Tinggi and Station 4 Raya Ambat Street in Pamekasan District

Data collection procedures

Environmental parameters

Environmental parameters were measured at each station to determine its conditions. According to Hariyanto et al. (2018), abiotic environmental factors influence animal groups' presence and population density, so the measurement can help determine the structure of animal communities in their habitat. Measured abiotic parameters were air temperature, soil temperature, water temperature, water pH, soil pH, water salinity, and soil moisture. The measurement was repeated thrice to improve the accuracy. The equipment used to measure the abiotic parameters were soil test kits for measuring soil temperature, soil pH, and soil moisture; thermometers for measuring air and water temperatures; and refractometers for measuring water salinity. Biotic environmental factors being investigated were the types and the most dominant mangrove species in the study area.

Crustacean and Mollusk sampling

Examination of Crustacean and Mollusk species in study area location was conducted by active sampling method, which was performed by Visual Encounter Survey (VES) and direct catching with scoop nets (Riper et al. 2010; Ng 2017). VES is preferred in time-constrained studies for observing species richness and abundance along a survey path (Heyer et al. 1994). VES was carried out by walking along the whole perimeter or accessible survey path and observing the signs or presence of target species (Tiberti et al. 2022); the samples acquired were caught and documented using a digital camera. In this study, the VES method was also used to maximize the results obtained due to limited access to samples due to the abundance of mangrove trees.

Measurement of distribution was conducted on 50 × 50 meter bot to the right and left of coastline along survey path. The distribution and abundance data collection method were refers to Ginantra et al. (2023), where species distribution was determined based on the presence and number of individuals of each species on each study area location. While the abundance of each species was calculated based on the number of individuals per unit area (m^2). The scientific names, numbers, and locations of observed samples were recorded. Identification of species was carried out using several guides, such as Marine Decapod Crustacea of Southern Australia: A Guide to Identification (Poore 2004); E-Booklet *Keanekaragaman Jenis Udang di Kawasan Sungai Bagandis, Kabupaten Tanah Laut* (Kaspul and Halang 2022); *Pedoman Identifikasi Udang* (Subordo Macrura Natantia) (Saputra 2008); Catalogue of the Marine Shells of Australia and Tasmania, Volume 1: Cephalopoda. Pteropoda. Gasteropoda (John 1892); E-Book *Keanekaragaman Moluska: Bivalvia, Gastropoda, Polyplacophora* (Steviana 2020); *Moluska: Karakteristik, Potensi, dan Pemanfaatan Sebagai Bahan Baku Industri Pangan dan Non Pangan* (Nurjanah et al. 2021). Identification is also done with the help of a global biodiversity database and software such as Global Biodiversity Information Facility (GBIF) and iNaturalist.

Data analysis

Analysis was performed qualitatively and quantitatively. Qualitative analysis was carried out by descriptive analysis, which provides an overview or description of a situation or condition without any treatment of the object being studied (Rompas 2014). Descriptive analysis was carried out through literature review, while the morphological record was depicted through documented Crustacea and Mollusk samples. Meanwhile, quantitative analysis was conducted by calculating several ecological indices; Shannon-Wiener diversity indices $[H' = \sum_{i=1}^{s} \text{pi} \ln \text{pi}]$, Margalef species richness indices $\left[R_1 = \frac{(S-1)}{\text{Ln}(N)}\right]$, Pielou evenness indices $\left[E_1' = \frac{H'}{H_{max}}\right]$, and Simpson dominance indices $\left[C = \Sigma \left[\frac{n_i}{N}\right]^2\right]$ (Hidayat and Nurulludin 2017). Results from calculation then analyzed regarding measured environmental parameters and station characteristics so that the correlation between ecological aspects of Crustaceans and Mollusks with the environmental factors in the study area can be acquired.

RESULTS AND DISCUSSION

Environment characteristics of sampling location

The environmental characteristics were examined from biotic and abiotic factors as benchmark parameters. The biotic parameter was the diversity of mangrove species at each station. The observation showed that the mangrove area at each station has certain similarities, including species, vegetation appearances, and substrate characteristics such in Table 1. Mangrove species found at the first station (Taddan) were *Avicennia marina* and *Sonneratia alba*, while mangrove species found at the second station (Song-Osong Beach) were *A. marina*, *Sonneratia caseolaris*, and *Rhizophora mucronata*. Mangroves at Taddan was mainly distributed as a group because mangroves reproduce by falling their seeds close to their progenitor (Muhsoni 2020). According to Zainuri et al. (2014), mangroves in Sampang Sub-district has a density of >1,500 trees/ha on 50.88% of its area, meaning that most of the mangroves has very dense vegetation. In Branta Tinggi, Pamekasan District, only one mangrove species was found, namely *R. mucronata*. Meanwhile, at Raya Ambat Street, Pamekasan District, two species of mangroves were found: *A. marina* and *R. mucronata*. The lower diversity of mangrove species in Pamekasan District compared to Sampang District can be caused by degradation since the mangrove forest areas were converted into residential, salt industrial areas, aquaculture, as well as the death of mangrove vegetation due to sand mining and plastic waste disposal (Sukandar et al. 2016).

The four stations were coastal areas located in the southern part of Madura Island and were directly adjacent to the Madura Strait. Each station area shaded by mangrove vegetation and open area. Stations 1 and 3 had mangrove vegetation substrates that tend to be muddy sand, while Stations 2 and 4 had mangrove vegetation substrates that tend to be sandy. Based on environmental parameters measurement, all stations had warm temperatures, tended to be neutral in pH, and possessed wet soil characteristics. The salinity level of the Madura Strait Waters ranged between 31.8 to 32.77 ppt (Abdulrohiim et al. 2022), so it can be said that the average water salinity at the study location tended to be low compared to Madura Strait. Sea depth can influence salinity, where the increase in salinity is directly relative to the sea depth level. The influx of fresh water in those areas also influences salinity (Suhana 2018). The lowest salinity level occurs in Station 2 due to ponds and brackish water flows. Based on the observations, local residents carried out various activities at all stations, such as parking boats, fishing, and gathering animals, such as crabs and clams, for consumption.

Crustacean diversity, abundance, and morphological record

From the data collection that has been done, it is known that there are two groups of taxa from the subphylum of Crustacea in the study area location, which are Decapoda and Cirripedia. The results showed that there were a total of 32 species of Crustacea consisting 13 families of Decapoda and 1 family from Cirripedia. Decapoda belongs to group of Malacostraca, which has modified first three pairs of thoracic limbs called maxillipeds as feeding organs appendages. While the last five pairs of thoracic limbs are involved in locomotion (Poore and Ahyong 2023). The decapod groups consist of prominent marine animals, such as shrimps, prawns, crabs, and lobsters. Meanwhile, Cirripedia belongs to the group Thoracica, which is characterized with confounded cephalic and thoracic segments. Cirripeds are permanently attached, even before their final metamorphosis, by tissue or cement (Darwin 1854). At the lower level of taxa, Crustacean at the study area location was composed of Anomura or hermit crabs (12.50%), Brachyura or true crabs (68.75%), Caridea or true shrimps (15.63%), and Cirripedia or barnacles (3.13%). The diversity and abundance of Crustacean species found in the study area is presented Table 2.

The majority of the Crustacean species discovered are typically found in intertidal habitats, such as beaches, estuaries, coral reefs, and mangroves. The most commonly found Crustacean species in study area location was *Balanus* sp. (barnacle), followed by *Clibanarius longitarsus* (common hermit crab). This explains why both of those species have the highest density on study area location. *Balanus* sp. or commonly known as barnacle is a species from class of Hexanauplia, infraclass of Cirripedia, order of Balanomorpha, and family of Balanidae. The members of the Balanidae are characterized by diametric growth and may have four or six wall plates. Balanids basal plate are calcareous, which attaches the animal directly to the substrate (Darwin 1854; Newman and Arnold 1976; Checa et al. 2019). Growth in height is achieved by growth of the plate parietes at their dorsal (basal) margin, while growth in width of the aperture takes place both at the cardinal growth surface of the radii and at the rostral growth margins of the alae. Radii grow towards the carina, whereas alae grow towards the rostrum (Checa et al. 2019). While *C. longitarsus* is belongs to family of Diogenidae, which characterized by poor calcification of the cephalothorax and uncalcified, asymmetric abdomen, and distinguished by the third pair of its maxillipeds are close together and the chelipeds are either equal or the left is larger than the right (Hazlett 1966). In all four stations, as many as 6 species have an even distribution, namely *Balanus* sp., *C. longitarsus*, *Uca dussumieri*, *Uca annulipes*, *Uca vocans*, and *Thalamita crenata*. In this study, Brachyura had the most diversity among other Crustaceans with 22 species from 8 families, followed by Caridea with 5 species from 3 families, Anomura with 4 species from 2 families, and Thoracica with a single species from 1 family. .

Brachyura is a group of Crustacean that often referred to as ‘true crabs’ that characterized by exoskeletons that are moulted for the animal to grow (even during larval stages), segmented bodies, stalked eyes, carapaces broader than they are long, similar appendages and mandibles. Most crabs, the first pair of legs (the chelipeds) is used for feeding and the legs terminate in curved, two-part claws or pincers (the chela) (Chris 2021). Caridea consist of shrimp-like decapods that belongs to the class of Malacostracea, which has a head consisting of a preantennular region bearing the eyes, followed by five segments with appendages (two pairs of antennae, three pairs of mouthparts), a thorax of eight segments, and an abdomen with usually six (sometimes seven) segments, most of which bear appendages. Another distinctive feature defining this group is the position of gonopores (female apertures on the sixth, male apertures on the eighth thoracic segment) (Bauer 2004). Anomura is an infraorder of decapod Crustaceans that are nearest relatives of the Brachyura and unifying group of hermit crabs (Paguroidea), squat lobsters, porcelain crabs (Galatheoidea), and mole crabs (Hippoidea). It main characters is very small size, reduced last walking legs, and has an uncalcified groove along the sides of the carapace (the *linea anomurica*). The last pair of walking legs is so reduced that most anomurans appear to have only six instead of eight walking legs at first sight (Hutchings et al. 2009) and Thoracica were characterized by confounded cephalic and thoracic segments, which has sessile parts that externally visible and divided into the operculum or opercular valves (*valvae operculares*) and the shell (*testa*) (Darwin 1854). Morphological record of Crustacean that found in study area location can be seen in Figure 2.

Based on the calculation results, the mangrove area in Sampang and Pamekasan Districts, Madura Island, Indonesia, has Crustacean diversity indices of 2.60 which means moderate, species richness indices of 4.05 which means high, evenness indices of 0.75 which indicates high evenness or stable community, and dominance indices of 0.10 which indicates no dominant species. The diversity, evenness, and dominance indices for each station does not show any significant difference, when compared to each other station. Meanwhile there were differences in the results of species richness between observation stations, where Stations 2 and 4 shows low, while Stations 1 and 3 shows moderate levels of species richness. Apart from that, Station 3 (Branta Tinggi) has the highest number of

Crustacean species, diversity, species richness, and evenness among other station in this study. The results of calculation can be seen in Table 3.

Table 1. Environment characteristics measured at the sampling station of mangrove ecosystem in Sampang and Pamekasan Districts, East Java, Indonesia

Parameter	Station			
	1	2	3	4
Mangrove species	*A. marina, S. alba*	*A. marina, S. caseolaris, R. mucronata*	*R. mucronata*	*A. marina, R. mucronata*
Water temperature (°C)	±30.67	±35.67	±34.33	±36
Soil temperature (°C)	±30.33	±34.67	±34.33	±35
Air temperature (°C)	±31.7	±36.33	±37.17	±36.33
Water pH	±7.6	±7.53	±7.37	±8.03
Soil pH	±6	±6.97	±6.8	±7.1
Water salinity (ppt)	±28.33	±19.67	±28.33	±32.67
Soil moisture	>10	>10	>10	>10
Substrate characteristics	muddy sand	sandy	muddy sand and soil	muddy sand with a bit of coral rock

Table 2. Diversity and abundance of Crustacean species at the sampling station of mangrove ecosystem in Sampang and Pamekasan Districts, East Java, Indonesia

Family	Species	Attendance in station				Density
		1	2	3	4	(Ind/5m^2)
Cirripedia: Thoracica						
Balanidae	*Balanus* sp.	●	●	●	●	80.8
Decapoda:Anomura						
Diogenidae	*Clibanarius cruentatus* (H.Milne-Edwards, 1848)	●	●	●	●	20
	Clibanarius longitarsus (De Haan, 1849)	●	●	●	●	56.2
Porcellanidae	*Petrolisthes armatus* (Gibbes, 1850)	●	-	●	-	2.2
	Petrolisthes asiaticus (Leach, 1820)	●	-	-	-	1
Decapoda: Brachyura						
Dotillidae	*Scopimera globosa* (De Haan, 1835)	-	●	-	-	12.4
	Ilyoplax orientalis (De Man, 1888)	-	-	●	-	10.2
Grapsidae	*Metopograpsus* sp.	-	-	-	●	0.4
	Metopograpsus frontalis (Miers, 1880)	-	●	●	●	6.6
	Pachygrapsus crassipes (Randall, 1840)	●	-	-	-	2.4
	Pachygrapsus marmoratus (Fabricius, 1787)	-	-	●	-	0.6
	Pachygrapsus plicatus (H.Milne Edwards, 1837)	●	-	●	●	2
	Planes minutus (Linnaeus, 1758)	-	●	-	-	1.8
Macrophthalmidae	*Macrophthalmus crassipes* (H.Milne Edwards, 1852)	●	-	-	-	0.2
Mictyridae	*Mictyris longicarpus* (Latreille, 1806)	-	●	-	-	0.8
Ocypodidae	*Uca annulipes* (H.Milne Edwards, 1837)	●	●	●	●	43.8
	Uca dussumieri (H.Milne Edwards, 1852)	●	●	●	●	47.2
	Uca lactea (De Haan, 1835)	●	●	-	●	28
	Uca perplexa (H.Milne Edwards, 1852)	-	-	●	-	5.2
	Uca vocans (Linnaeus, 1758)	●	●	●	●	48.2
	Ocypode cordimana (Latreille, 1818)	-	●	-	-	1.2
Portunidae	*Charybdis helleri* (A.Milne-Edwards, 1867)	-	-	●	●	2.2
	Thalamita crenata (Rüppell, 1830)	●	●	●	●	15.4
	Thalamita prymna (Herbst, 1803)	-	-	●	-	1.8
Sesarmidae	*Episesarma versicolor* (Tweedie, 1940)	●	-	●	-	11.4
	Parasesarma pictum (De Haan, 1835)	●	-	●	-	4.2
Xanthidae	*Leptodius exaratus* (H.Milne Edwards, 1834)	●	-	-	●	1.6
Decapoda: Caridea						
Alpheidae	*Alpheus digitalis* (de Haan, 1844)	-	●	●	-	3.4
	Alpheus sp.	●	-	●	-	0.6
	Arete indicus (Coutière, 1903)	-	-	-	●	3.6
Atyidae	*Caridina* sp.	-	●	-	-	0.6
Palaemonidae	*Macrobrachium* sp.	-	●	-	-	3

Decapoda: Anomura


Clibanarius cruentatus


Clibanarius longitarsus


Petrolisthes armatus


Petrolisthes asiaticus

Decapoda: Brachyura


Charybdis hellerii


Episesarma versicolor


Ilyoplax orientalis


Leptodius exaratus


Macrophthalmus crassipes


Metopograpsus frontalis


Metopograpsus sp.


Mictyris longicarpus


Ocypode cordimana


Pachygrapsus crassipes


Pachygrapsus marmoratus


Pachygrapsus plicatus


Parasesarma pictum


Planes minutus


Scopimera globosa


Thalamita crenata


Thalamita prymna


Uca dussumieri


Uca lactea


Uca annulipes


Uca perplexa


Uca vocans

Decapoda: Caridea

Alpheus digitalis | *Alpheus* sp. | *Arete indicus* | *Macrobrachium* sp. | *Caridina* sp.

Cirripedia: Thoracica

Balanus sp.

Figure 2. Crustacean species in mangrove ecosystem in Sampang and Pamekasan Districts, East Java, Indonesia

Mollusk diversity, abundance, and morphological record

The study documented 24 Mollusk species from 17 families in the study area location, which composed of 3 classes, namely Gastropoda (58.33%), Bivalvia (37.5%), and Polyplacophora (4.17%). Gastropoda has the highest number of species among other families that consists of 14 species, and at the same time having the highest average population density. The most abundant species which also occurred all stations were *Pirenella alata* and *Pirenella cingulata*. Both are the same genera commonly found in several shores in the Pacific Ocean, Indian Ocean, to the Mediterranean Sea. This species is also often found in mangrove areas and mudflat substrates associated with outer to mid-range estuaries (Reid and Ozawa 2016: Wintah 2018). *Pirenella* sp. is usually found in a very dense distribution, resulting in high abundance. The observations also revealed that most of the Mollusks lived in a colony. Several Mollusk species, such as *P. alata, P. cingulata, P. maculata,* and *N. nigrita*, were seen attached to substrates such as sediment, coral rocks, and mangrove roots. While some others were only found by their shells, which may exist because sea currents swept them away. The diversity and abundance of Mollusk species found in the study area is presented Table 4.

Mollusk is a phylum of animal that are hugely successful to spread through marine environment and inhabit various ecosystems such as seabed, open waters, ocean surfaces, to shores (Gilpin 2006). From the several Mollusk families that found, Gastropoda being the most diverse on study area location, followed by Bivalvia and Polyplacophora. Gastropoda is the largest class of Mollusk and exhibit enormous diversity in form of shape and habitat. Limpets, top shells, abalone shells, periwinkles, slipper shells, and whelks are well known to observe. They are possess a muscular foot for creeping or burrowing, a head with sensory tentacles and eyes, a characteristic rasping radula (absent in some), and the mantle secretes the shell to provide a shelter (Carlton 2007). Typical character of gastropods are the head and foot arise from the same region, so they called head-foot or cephalopodium, which making it very difficult to differentiate where the head ends or the foot begins (Ray 2017). A lot of marine gastropods are benthic and mainly epifaunal that lived in the deep sea to the water surface (Santhanam 2019). The majority of gastropods that found in this study were species that commonly live in littoral zone, and species from Potamididae family was the most diverse and dominant among others Mollusk, including *Pirenella* sp. which is typically can only be found on mangrove ecosystems (Egonmwan 2008; Arbi et al. 2019).

Other Mollusk classes that found were Bivalvia and Polyplacophora. Bivalvia is the second largest class within the Mollusk, which characterized by two mantle lobes cover the body organs and secrete the two shell valves that are hinged dorsally (Gosling 2015). Bivalve are thought to have originated in warm shallow euhaline coastal waters and gradually invaded estuaries and brackish systems, as well as the reaches of the world ocean. Because adults forms of the majority of these animals are benthic or bottom dwelling, many different evolutionary adaptations to the benthic habitat have occurred (Dame 2012). Meanwhile Polyplacophora or chitons include about 600 extant species that entirely marine. They inhabit hard bottoms and rocky coasts in all of the world's ocean. Although commonly intertidal, living chitons have been dredged from waters as deep as 7000 meters (McKenzie and Parker 2019). Most chitons are grazers, feeding by scraping matter from the substrates using a complex radula with some teeth that have cutting edges reinforced with magnetite (Scheltema et al. 2001). Morphological record of Mollusk that found in study area location can be seen in Figure 3.

According to the calculation results, the mangrove area in Sampang and Pamekasan District, Madura Island, Indonesia, has Mollusk diversity indices of 2.61 which means moderate, species richness indices of 3.02 which means moderate, evenness indices of 0.82 which indicates high evenness or stable community, and dominance indices of 0.11 which indicates no dominant species. The data from calculation also shows that each station has moderate diversity, low species richness, high evenness or stable community, and no dominant species. Apart from that, Station 4 (Raya Ambat Street) has the highest number of Mollusk species, diversity, species richness, and evenness among other station in this study. The results of calculation can be seen in Table 5.

Table 3. Diversity, species richness, evenness, and dominance indices calculation of Crustacean from mangrove ecosystem in Sampang and Pamekasan Districts, East Java, Indonesia

Calculation	Station				Entire study area location
	1	2	3	4	
Number of species found	17	16	18	14	32
Diversity indices	2.25	2.29	2.49	2.13	2.60
Species richness indices	2.57	2.44	2.66	2.07	4.05
Evenness indices	0.79	0.83	0.86	0.81	0.75
Dominance indinces	0.14	0.14	0.10	0.14	0.10

Table 4. Diversity of Mollusk species at the sampling station of mangrove ecosystem in Sampang and Pamekasan Districts, East Java, Indonesia

Family	Species	Location found				Density ($Ind/5m^2$)
		1	2	3	4	
Bivalvia						
Cardiidae	*Fulvia tenuicostata* (Lamarck, 1819)	●	-	-	●	4.2
Isognomonidae	*Isognomon alatus* (Gmelin, 1791)	-	-	-	●	10.2
Mytilidae	*Perna* sp.	●	-	-	-	1.4
Pinnidae	*Atrina fragilis* (Pennant, 1777)	-	●	-	-	2.4
Solenidae	*Solen* sp.	-	●	-	-	7.2
Veneridae	*Gafrarium pectinatum* (Linnaeus, 1758)	●	-	●	-	6.8
	Marcia hiantina (Lamarck, 1818)	●	●	-	●	28
	Marcia japonica (Gmelin, 1791)	-	●	-	-	2.4
	Placamen chloroticum (R.A.Philippi, 1849)	-	-	-	●	3.4
Gastropoda						
Ampullariidae	*Pomacea maculata* (Perry, 1810)	-	-	-	●	7.8
Assimineidae	*Assiminea brevicula* (L.Pfeiffer, 1855)	-	-	-	●	20.4
Buccinidae	*Buccinum sp.*	-	-	-	●	12.4
Cerithiidae	*Cerithium carnaticum* (Melvill & Standen, 1898)	●	-	-	●	25.2
Littorinidae	*Littoraria angulifera* (Lamarck, 1822)	-	●	-	●	20
Naticidae	*Natica gualteriana* (Récluz, 1844)	-	-	-	●	6.4
Neritidae	*Nerita nigrita* (Röding, 1798)	●	-	-	●	14.8
	Nerita lineata (Gmelin, 1791)	-	-	●	●	18.6
Olividae	*Oliva irisans* (Lamarck, 1811)	-	●	●	●	12.2
Potamididae	*Pirenella alata* (R.A.Philippi, 1849)	●	●	●	●	94.8
	Pirenella cingulata (Gmelin, 1791)	●	●	●	●	72
	Telescopium telescopium (Linnaeus, 1758)	-	●	●	-	4,2
	Terebralia sulcata (Born, 1778)	-	●	-	-	10.4
Trochidae	*Umbonium vestiarium* (Linnaeus, 1758)	-	●	●	●	18.2
Polyplacophora						
Chitonidae	*Chiton* sp.	-	●	-	-	0.4

Table 5. Diversity, species richness, evenness, and dominance indices calculation of Mollusk from mangrove ecosystem in Sampang and Pamekasan Districts, East Java, Indonesia

Calculation	Station				Entire Study Area Location
	1	2	3	4	
Number of species found	8	12	7	16	24
Diversity indices	1.74	2.23	1.63	2.57	2.61
Species richness indices	1.16	1.86	1.01	2.22	3.02
Evenness indices	0.84	0.90	0.84	0.93	0.82
Dominance indinces	0.21	0.13	0.23	0.09	0.11

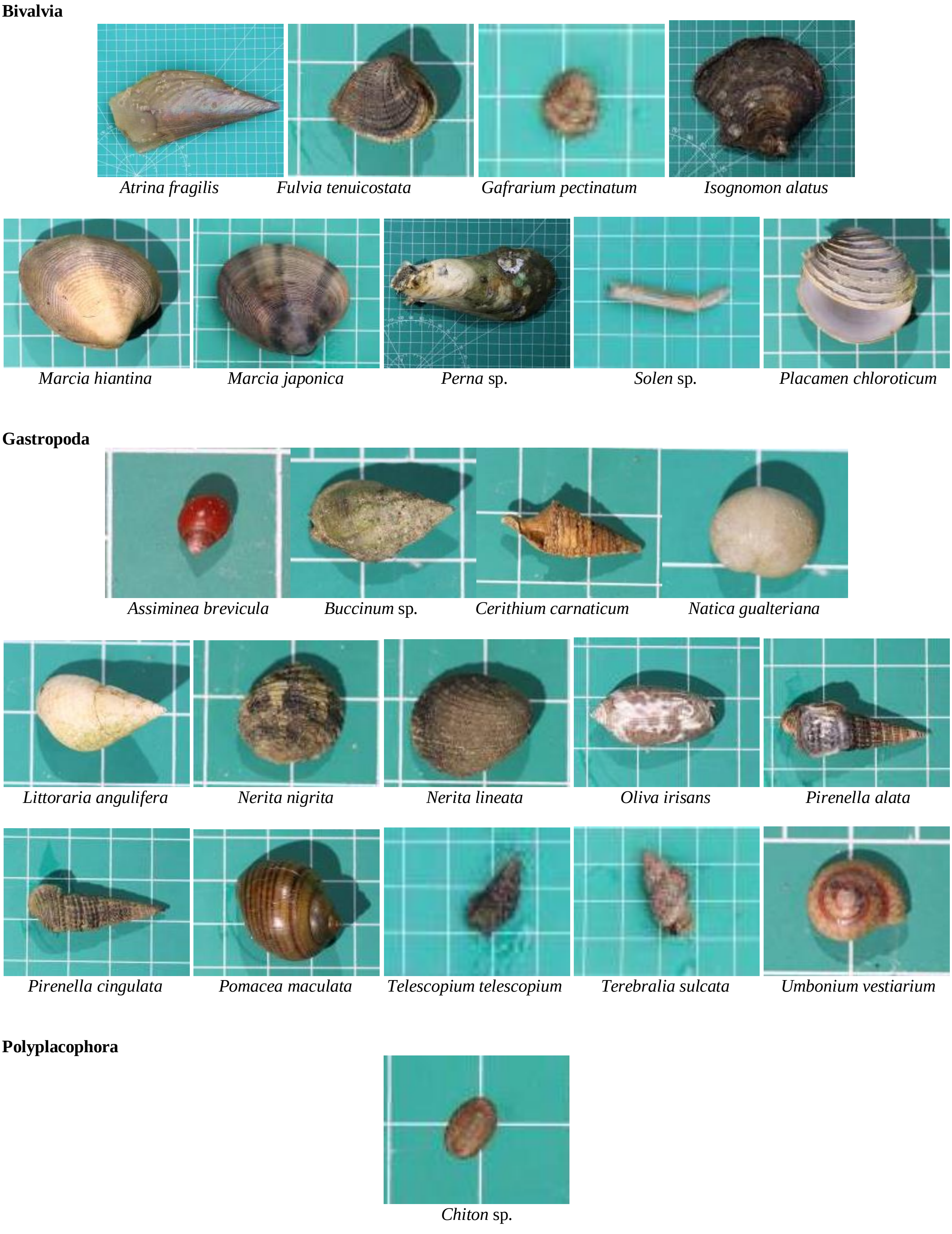

Figure 3. Mollusk species in mangrove ecosystem in Sampang and Pamekasan Districts, East Java, Indonesia

Discussion

In this study, the four stations were mangrove forest areas that had different vegetation, environmental characteristics, and species composition of Crustaceans and Mollusks. Based on the data obtained, 32 species of Crustacea and 24 species of Mollusks were found. The abundance of two Crustacean species that being the most found on study area location: *Balanus* sp. and *Clibanarius* sp., can be occurred mainly due to its intrinsic characters; reproductive behavior, growth rate, adaptability, and habitat suitability (Noda 2004; Rudi and Fadli 2009, Fitriani et al. 2024). Apart from that, biological behavior factors of each species also greatly influence its density. *Balanus* sp. or barnacles are a highly successful group in global dispersion and are usually found in aggregations of conspecifics and other fouling organisms (Newman and Arnold 1976; Torres et al. 2012). Barnacles can be transported as fouling on the hull of ships or as larvae in ballast water. Its larvae can survive for a long time and settle on hulls of ships staying in harbours and then can grow very quickly while carried away to other areas. Many barnacles are benefited from this condition to reach new regions where they often successfully colonized harbor installations, pontoons, and floating objects, such as buoys and other hard substrata (Torres et al. 2012). Barnacles can also secrets arthropodine compounds that able to attract other barnacles to gather and form a colony (Boesono 2010; Rizki et al. 2013). *Clibanarius* sp. or common hermit crab is a Crustacean that generally found in the Indo-West-Pacific tropical mangrove forests and recorded in several countries (Richmond 1997; Hossain et al. 2015). Common hermit crab inhabits benthic, littoral, rivers, creek mouths, and mangrove habitats, typically mud to muddy-sand substrates (Davie 2002). Those habitat characteristics were very suitable with the description of the study area location, which has the same substrate characteristics and is supported by certain environmental factors, making it an ideal habitat for the common hermit crab. In addition, a study by Varadarajan and Subramoniam (1982) shows that stable environmental temperature throughout the year, moderate changes in salinity, and plenty of nutrient availability may well be conducive support for continuous reproduction for species of hermit crabs.

The highest number and density of Mollusk that found on study area location was *P. alata* and *P. cingualata* that belongs to the Potamididae family, which typically can only be found in mangrove ecosystems (Egonmwan 2008; Arbi et al. 2019). They inhabit the mudflats of the mangrove swamps and quiet waters where the substratum is muddy and rich in detritus. They also have a habit of migrating to the edges of the water and congregating under tufts of grasses and breathing root of the mangrove plants, which shading them from direct sun light. The preference for muddy deposits may be correlated with the species being deposit feeders, taking in the mud, and digesting the detritus and other organic matter (Egonmwan 2008). Mangrove habitat provides shelter to this species, thereby supporting its growth population and, hence, abundance. Moreover, *Pirenella sp.* can starve for up to 28 days, adding to its ecological tolerance and population survivorship (Bhatt et al. 2020). *Pirenella* sp. is considered to be an indicator for and can be used as source of information on the bioavailability of contaminants in the ecosystem. In addition, this genus can also show changes in the physical environment of the mangrove ecosystem that can provide real effects on organism abundance and biodiversity (Auliatuzahra et al. 2022).

The population density of Crustacean ranges from 0.6-80.8 ind/5m^2, while for Mollusk ranges from 0.4-94.8 ind/5m^2. The range of Mollusk population density is higher because on study area location Mollusks are more often found in groups in larger numbers. In addition, they are also found on more varied substrate types such as coral rocks, tree roots, sand, mud, trunks, to ship’s hull. Based on indices calculation, Crustacean and Mollusk in study area location indicates moderate diversity, high evenness or stable community, and no dominant species. But species richness of Crustacean indicates high, while species richness of Mollusk indicates moderate. The mangrove environment in both locations has an ecosystem condition that is suitable and able to support life and diversity of Crustaceans and Mollusk, both for species that have associations with mangrove habitats or species that live in intertidal habitats. The lower species richness of Mollusk than Crustaceans can be caused by human activities, due to the community around the four stations who often look for small fish and macrozoobenthos as food when the sea begins to recede. Mollusk has slower movements compared to Crustacean, which makes them easier to catch. Station with the highest number of Crustacea species, diversity, species richness, and evenness is Station 3 (Branta Tinggi), while for Mollusk is Station 4 (Raya Ambat Street). Both stations do not have a significant difference abiotic characteristics than other stations. We presume that the main factor causing higher diversity and ecological indices at Stations 3 and 4 is it has wider mangrove area and supported by denser vegetation that can provide better shelter for Crustacean and Mollusk. This also supported by Lee et al. (2017), which mentioned that the size of diversity, abundance, and species richness of mangrove biota may correlated with forest characteristics (e.g. tree density, biomass).

Compared with previous research that related to Crustacean and Mollusk diversity in Sampang and Pamekasan Districts, this study may be recorded one of the largest number of Crustacean and Mollusk species in location. Several research that has been conducted on the same station with this study that related to Crustacean and Mollusk diversity were: Pratiwi and Muhsoni (2021), in Taddan, Camplong Sub-District, Sampang District, whom studied mangrove ecotourism potential and found 5 Crustacean and 20 Mollusk species; Islamy and Hasan (2020), in Raya Ambat Street, Tlanakan Sub-District, Pamekasan District, whom studied the diversity of mangrove snails (Mollusca: Gastropoda) and found 15 species of it. Those research that has been carried out were limited to studying certain classes or genera, or only presents incomplete Crustacean and Mollusk biodiversity data because the focus of their study is not on diversity. However, data from previous research will be very helpful in filling the gaps on this study. According to Cappenberg et al. (2021), the diversity of Crustaceans and Mollusks in mangrove ecosystems is always temporal and dynamic and depends on the response and pressure the ecosystem receives. One environmental factor that can affect the condition of the mangrove ecosystem is seasonal variation. According to information collected from residents around the study area, the mangrove area that is the sampling location will be heavily submerged by high tide during the rainy season. Surely, this could influence the structure of the Crustacean and Mollusk communities

The findings of this study may support the evidence from several research that stated mangrove ecosystems have high potential as biodiversity hotspots. Mangrove can provide stable and essential ecosystem services by protecting shoreline areas against tidal currents, waves, and eutrophication (Koh et al. 2018), which can be a crucial factor needed by intertidal organisms to support their life, such as Crustacean and Mollusks. Based on this study, several Crustaceans and Mollusk found, such as species from the family Ocypodidae and Potamididae, have certain associations with the environment of mangrove areas, so their presence can help provide an overview of conditions of the mangrove ecosystem in Sampang and Pamekasan Districts. Even so, to studied the diversity and population dynamics comprehensively, further research using more complex methods is needed, such as trapping and DNA analysis, as well as long-term monitoring to capture seasonal variations. So, a more holistic view of Crustacean and Mollusk complexity as a key role species on mangrove area can be provided.

In conclusion, the mangrove ecosystem in Sampang and Pamekasan Districts has certain similarities, i.e. both were composed by vegetation of *S. alba*, *A. marina*, *S. caseolaris*, and *R. mucronata*. Stations 1 and 3 had mangrove vegetation substrates that tend to be muddy, while Stations 2 and 4 had mangrove vegetation substrates that tend to be sandy. The environmental parameters measurement showed that the study area location had warm temperatures, wet soil, neutral pH, and relatively low salinity compared to Madura Strait. On study area location, as many as 32 Crustacean species was obtained consisting of 13 families from Decapoda and 1 family from Cirripedia. The most commonly found Crustacean species in study area location was *Balanus* sp. (barnacle), followed by *C. longitarsus* (common hermit crab). Based on calculations results, Crustacean diversity indices was 2.60 which means moderate, species richness indices was 4.05 which means high, evenness indices was 0.75 which indicates high evenness or stable community, and dominance indices was 0.10 which indicates no dominant species. Station 3 (Branta Tinggi) has the highest number of Crustacean species, diversity, species richness, and evenness among other station. Moreover, this study documented 24 Mollusk species from 17 families in study area location consisting of 14 Gastropoda, 9 Bivalvia, and 1 Polyplacophora. The most abundant Mollusk species and also occurred all stations were *P. alata* and *P. cingulata*. According to the calculation results, the Mollusk diversity indices was 2.61 which means moderate, species richness indices was 3.02 which means moderate, evenness indices was 0.82 which indicates high evenness or stable community, and dominance indices was 0.11 which indicates no dominant species. Station 4 (Raya Ambat Street) has the highest number of Mollusk species, diversity, species richness, and evenness among other station. The abundance of *Balanus* sp., *Clibanarius* sp., *P. alata*, and *P. cingulata* can be occurred mainly due to their intrinsic characters, reproductive behavior, growth rate, adaptability, and habitat suitability. The main factor causing higher diversity and ecological indices at Stations 3 and 4 is presumed by its wider mangrove area and supported by denser vegetation that can provide better shelter for Crustacean and Mollusk.

ACKNOWLEDGEMENTS

We would like to thank all those involved in and who contributed to the progress of this research. The cooperation and sophistication of our mentor, field guide, and friends also made this research run well and successfully.

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INDO PAC J OCEAN LIFE
Volume 8, Number 2, December 2024
Pages: 72-83

P-ISSN: 2775-1961
E-ISSN: 2775-1953
DOI: 10.13057/oceanlife/o080203

Review: The nutritional value and health benefits of *kawakawa* (*Euthynnus affinis*)

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Manuscript received: 8 June 2024. Revision accepted: 22 October 2024.

Abstract. *Rahma HS, Ayuningtyas HR, Nabila I, Annafi DN, Nurwulandari M, Indrawan M, Dadiono MS, MD Naim D, Setyawan AD. 2024. Review: The nutritional value and health benefits of* kawakawa (Euthynnus affinis). *Indo Pac J Ocean Life 8: 72-83. Kawakawa* (*Tuna*), or *Euthynnus affinis* (Cantor, 1849), is a species of pelagic fish of the Scombridae family with a vast habitat and distribution in tropical and subtropical waters in the Indo-Pacific region. This literature review aims to provide an understanding of the habitat, morphological characteristics, nutritional content, and benefits of *kawakawa* for health. *Kawakawa* prefers warm waters with a temperature of 20-30°C. As a pelagic fish, *kawakawa* spends most of its life in the open water column and away from the seabed. *Kawakawa* morphologically has unique characteristics, namely oblique and curved black stripes on the ribs and the presence of a pattern of black stripes between the abdomen and fins. This fish can grow to a maximum weight of 14 kg and a maximum fork length (FL) of 100 cm. The nutritional content of *kawakawa* is diverse, and it includes protein, omega-3, omega-6, selenium, vitamin D, and DHA. The protein content of *kawakawa* ranges from 20 to 25%, with 0.87% fat, which is lower than that of other fish species. With its high protein, low fat, and strong omega-3 fatty acid profile, *kawakawa* has a high overall nutritional value, making it a nutrient-dense food choice. The nutritional content in *kawakawa* has significant health benefits, providing reassurance of its value in preventing stunting, reducing heart risk, preventing cancer, maintaining eye health, increasing body immunity, preventing anemia, and maintaining bone health.

Keywords: Benefits, health, *kawakawa*, nutrition

INTRODUCTION

Tuna or *kawakawa* (*Euthynnus affinis* Cantor, 1849) are large pelagic fast swimmers that live in groups (Hawkins et al. 2014; Bar et al. 2015; Harahap et al. 2022). *Kawakawa* live in tropical and subtropical waters, such as the Indian, Pacific, Mediterranean, and Black Oceans. Among the *neritic tuna* that live in the coastal waters of India, *kawakawa* is the most widely found species (Mehanna 2024). *Kawakawa* is a promising aquaculture due to its rapid development and increasing demand (Yazawa et al. 2016). *Kawakawa* belong to the neritic species, live in water temperatures ranging from 18 to 29°C, and form a multispecies group based on size (Syamsuddin et al. 2018). *Kawakawa* tend to form multispecies groups depending on their size, ranging from 100 to more than 5,000 individuals (Syahliani et al. 2021; Widiastuti et al. 2023). Living at a depth of 200 meters, these fish are epipelagic marine species (Sivadas et al. 2020). However, according to Agustina and Sulistyaningsih (2022), this species appears in groups that reach a depth of 400 meters. Large pelagic fish have no definite fishing ground; the catchment area constantly changes and moves in response to changing environmental conditions, causing the fish to automatically choose a more suitable habitat (Safruddin and Hidayat 2023). *Kawakawa* has varied diets, so it can absorb more elements from its food sources, increasing its nutritional value, which enhances its nutritional value, making it an intriguing species for further study.

Kawakawa has long been recognized as an important source of nutrients for human health (Djunaidah 2017). Among the various types of marine fish, the *kawakawa* has nutritional value and health benefits (Khoa et al. 2021). As a pelagic species widespread in tropical and subtropical waters around the world (Sutton et al. 2017), this fish has been the subject of exciting nutrition and public health studies because of its nutritional content. Although *kawakawa* has long been consumed, in-depth research on its nutritional content is still developing. Numerous studies reported various essential nutritional components in *kawakawa* (Danitasari and Rahmawaty 2024). The protein content in this fish plays a vital role in forming and maintaining body tissues because it contains all the essential amino acids needed by the body. In addition, the fat content found in *kawakawa* is relatively low (Abou-Taleb et al. 2019). However, there are beneficial omega-3 fatty acids such as EPA and DHA in the fat of *kawakawa* that have been shown to benefit the heart, brain, and nervous system.

Sea fish contains essential vitamins, such as vitamins A, D, B12, and E, also found in *kawakawa* (Rifat et al. 2023). With various complete and balanced nutritional components, consuming *kawakawa* is a healthy diet to support human health (Murti et al. 2022). In addition, *kawakawa* is also known as a source of nutrients that are low in cholesterol and high in protein (Munubi et al. 2022). Therefore, it is a popular dietary choice for individuals concerned about heart health and striving to maintain a healthy weight. The balanced fat content, especially omega-3 fatty acids, makes it an attractive option for maintaining optimal brain function and reducing the risk of health problems such as heart disease and neurodegenerative diseases; it also provides reassurance about its health benefits. *Kawakawa,* known as *ikan tongkol* (Sayuti et al. 2022), is quite popular in various communities. People like that this fish can provide a lot of nutrients at an affordable price (Musafira and Sikanna 2023). Absah and Hasanah (2022), due to its nutritional content and taste, it is widely processed into various types of food. However, not many people know that *kawakawa* has a lot of benefits for consumers. There are limited studies on the benefits of *kawakawa*, which has high nutrients and health benefits. This review can clearly understand its nutritional profile and reveal the potential health benefits of consuming *kawakawa*. This literature review aims to provide an understanding of the habitat and morphological characteristics of *kawakawa* and their nutritional content and health benefits.

HABITAT AND DISTRIBUTIONS OF *KAWAKAWA* (*Euthynnus affinis*)

Kawakawa is a species of pelagic fish of the family Scombridae with an expansive habitat and distribution (Jesila et al. 2023). The habitat and distribution of *kawakawa* are important factors affecting their survival and population dynamics. *Kawakawa* is widely distributed in tropical and subtropical waters of the Indo-Pacific region (Binashikhbubkr et al. 2023). In the Indian Ocean and the Pacific Ocean, this fish is widely found in the coastal waters of India, Sri Lanka, and Maldives, along the coast of East Africa, including the Persian Gulf and the Red Sea. Their presence in these areas indicates a high adaptability to various conditions of coastal waters. In the coastal waters of India, *kawakawa* can be found around the western and eastern coasts, with significant populations in the Bay of Bengal and the Arabian Sea. Sri Lanka is also an important habitat, especially in coastal areas rich in coral reefs and seagrass beds. With its distinctive atoll ecosystem, the Maldives provides an ideal *kawakawa* environment. The clear, warm waters support an abundance of plankton and small fish, the primary food source for *kawakawa*. Along the East African coast, from Somalia to Mozambique, nutrient-rich waters are home to large populations of *kawakawa*. The Persian Gulf and the Red Sea are important habitats, with relatively warm and nutrient-rich water conditions supporting *kawakawa* life. Its presence in these areas indicates a high adaptability to various conditions of coastal waters.

In the Pacific Ocean, *kawakawa* is distributed from Southeast Asian waters such as Indonesia, Malaysia, and the Philippines (Husain et al. 2021). This fish is often found in Java, Sulawesi, and Banda Sea. The Java Sea, with its shallow waters and rich in nutrients from river courses, is one of the main locations for the *kawakawa*ery. The Sulawesi and Banda seas also provide a supportive habitat for these fish with their greater depths and abundant coral reef ecosystems (Reuter et al. 2022). Meanwhile, in Malaysia and the Philippines, the waters around the Malay Peninsula and the Philippine Islands are a suitable habitat for *kawakawa*. Their distribution extends to Japan and Australia. In Japan, *kawakawa* is found around Ryukyu and Kyushu because warmer water and nutrient-rich oceans create an ideal environment (Ohshimo et al. 2024). In Australia, this fish is distributed along the eastern and northern coasts. On the east coast, from Queensland to New South Wales, *kawakawa* are found in coastal waters rich in coral reefs and seagrass beds, while on the north coast, they inhabit shallow, warm waters abundant in nutrients. *Kawakawa* are also found in Pacific Islands such as Papua New Guinea, Fiji, and Polynesia. With its long coastline and rich marine ecosystem, Papua New Guinea supports a significant population of *kawakawa*. Fiji and Polynesia have rich marine ecosystems, providing a life-supporting environment for these fish. Extensive coral reefs and atoll ecosystems in Fiji, Polynesia, are ideal water conditions for *kawakawa*, with abundant feed sources and stable water conditions (Harding et al. 2022).

The distribution of *kawakawa* in various regions shows they are adaptable to various tropical and subtropical water conditions. These adaptations include adapting to variations in temperature, salinity, and food availability. *Kawakawa* can be found in waters with strong currents and diverse environmental conditions (Jumsar et al. 2023), ranging from shallow waters near the coast to deep waters around coral reefs. Habitats with complex structures, such as coral reefs and seagrass beds, provide protection and enlargement areas for *kawakawa*. Coral reefs offer a place to forage and protect from predators (Rogers et al. 2018). In regions such as Indonesia, the Philippines, and Malaysia, abundant coral reefs create an ideal environment for *kawakawa* to survive and breed. In addition, strong currents in the ocean help spread larvae and juveniles of *kawakawa*. These strong currents carry nutrients that are essential for the production of plankton, as well as helping in the distribution of fish populations (Ardyna and Arrigo 2020). In the Indian and Pacific Oceans, the North and South Equatorial currents play an important role in determining the geographical distribution of *kawakawa*. This adaptation also allows *kawakawa* to utilize various food sources, including plankton, small fish, and crustaceans. The ability of fish to migrate and explore different water areas enables them to find and utilize available resources, thus supporting their survival and population growth in various habitats (Tamario et al. 2019). GBIF has 1,473 point occurrences of *kawakawa* with a distribution as shown in Figure 1 (GBIF 2024).

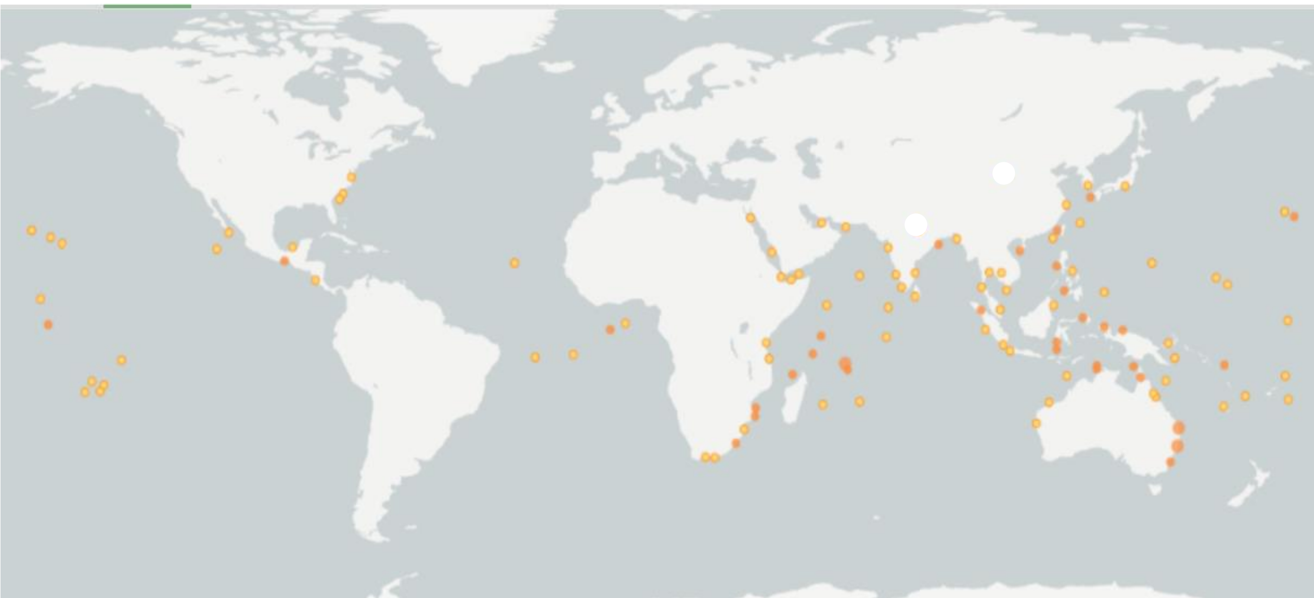

Figure 1. The world distribution of *kawakawa* (*Euthynnus affinis* Cantor, 1849) (GBIF 2024)

As a pelagic fish, *kawakawa* spends most of its life in the open water column and away from the seabed (Sianturi et al. 2023). These fish generally inhabit waters near the coast (Patmiarsih et al. 2023). In addition, they swim up to the open sea, especially in deeper waters around coral reefs and waters rich in nutrients (Wiratmini and Wijana 2024). They are active inhabitants of vast, open waters, moving freely without being tied to the seabed. It allows *kawakawa* to navigate and search for food at various depths and regions. In addition to avoiding predators, this pelagic pattern of life also enables them to explore broader areas in search of food sources. *Kawakawa* often swims near the surface to a depth of about 200 meters (Hamjan and Mallawa 2020). This adaptation allows them to exploit the abundant food resources at various ocean depths. Fish habitats are strongly influenced by marine environmental conditions, such as water temperature, food availability, and habitat structure (Husain et al. 2021). *Kawakawa* thrive in warm waters with temperatures ranging from 20-30°C, typically found in tropical and subtropical regions with strong currents and nutrient-rich waters that support abundant plankton and small fish as their primary food sources (Koropitan et al. 2021). Coral reefs and seagrass beds are crucial habitats, providing protection and ideal rearing areas for these fish (Whitfield 2017).

Ecologically, *kawakawa* plays an important role in the marine food chain. This fish is an active predator that feeds on various types of small fish, crustaceans, and plankton (Renjith et al. 2023). Its role as a predator ensures that its prey population remains controlled, thus helping to maintain the balance of the marine ecosystem. *Kawakawa* have a varied diet and do not depend on one type of prey. It shows their flexibility in finding food and adjusting to the resources in their habitat. As a predator, *kawakawa* interacts with various species of small fish and crustaceans that become its prey. These interactions are important in maintaining the structure of marine communities. In addition, *kawakawa* also interacts with other predators, such as sharks and giant tuna. Competition for food resources and living space with other species also affects the distribution and abundance of *kawakawa* in various habitats. The existence and distribution of fish in the sea are dynamic, constantly changing or moving following the movement and changes in environmental conditions (Nagi et al. 2023). This phenomenon reflects the high adaptability of *kawakawa* to aquatic conditions. They can survive in various aquatic conditions as long as the temperature and availability of food meet their needs. This adaptation includes tolerance to temperature variations and the ability to find and utilize available food sources in various environmental conditions of its habitat. Pelagic fish are fast swimmers (Laksono et al. 2024). High swimming speed gives *kawakawa* an advantage in chasing prey and avoiding predators. This capability also allows them to migrate long-distance efficiently.

The ability of *kawakawa* to migrate and adapt quickly to environmental changes helps them maintain stable populations in various water areas (Tamario et al. 2019). Seasonal migration is an important adaptation for *kawakawa*. The fish move to deeper waters or closer to the shore depending on water temperature and food availability (Erzad et al. 2018). In the summer, they will migrate to the waters with lower temperatures and deeper altitudes, searching for food and more comfortable conditions. Conversely, in the winter, they approach the coast with warmer water. Fish migration helps avoid unfavorable environmental conditions and maximizes the chances of getting more food (Xu et al. 2020). These fish often follow migratory patterns related to the movement pattern of ocean currents and seasonal water temperature changes.

Global climate change that causes an increase in sea temperature and changes in ocean current patterns affect the distribution of *kawakawa*. Rising water temperatures force *kawakawa* to migrate to colder regions, while ocean currents change the distribution of plankton and other prey. *Kawakawa*'s adaptation to these environmental changes determines their ability to survive in the long term. The behavior and ecological responses of *kawakawa* species to environmental changes are crucial to understanding their habitat and distribution in different water areas (Bernal et al. 2017). This adaptive migratory behavior also allows *kawakawa* to avoid areas with high predator pressure or less favorable environmental conditions, such as waters with very low or very high temperatures. In addition, migration allows them to exploit regions with plentiful seasonal food supplies (Kubelka et al. 2022). *Kawakawa* migration patterns that follow water temperature and food availability reflect complex ecological adaptations. This seasonal migration allows them to take advantage of optimal environmental conditions throughout the year. Migration to deeper waters or closer to the coast depends on the season and water temperature changes, ensuring they remain in the most suitable habitat for growth and reproduction.

Nutrient-rich aquatic conditions are often the ideal habitat for *kawakawa* (Sartimbul et al. 2017). The abundance of nutrients in these waters is usually caused by upwelling, where nutrient-rich water from the seabed rises to the surface (Waas et al. 2023). These conditions favor the abundant growth of plankton, which then becomes the primary food source for many small fish, including *kawakawa*. Thus, the presence of *kawakawa* is often an indicator of the health of marine ecosystems. These fish also avoid polluted waters or have poor water quality, so their populations decline dramatically in heavy pollution areas. Overall, the adaptation and lifestyle of the *kawakawa* as pelagic fish gives them a competitive advantage in finding food and survival. With the ability to explore various depths and areas of the ocean, *kawakawa* can make optimal use of marine resources and ensure its population's survival and growth (Hawkins and Popper 2017). The ability to navigate various environmental conditions allows *kawakawa* to maintain a stable population despite the changing environmental pressures on its habitat.

MORPHOLOGY OF *KAWAKAWA* (*Euthynnus affinis*)

Morphology is a branch of science that studies the body's shape, size, and structure. Fish morphology is used to distinguish fish species and even closely related species, and the shape and size of the fish body are important instruments in morphology (Binashikhbubkr et al. 2024). *Kawakawa* is one of the marine biological resources with relatively high economic potential; hence, fishermen target it as a fishery product (Hasibuan et al. 2023).

Kawakawa is a pelagic from the Scombridae family that lives in groups (Tangke et al. 2021). The body shape of the *kawakawa* is elongated like a torpedo, slender, streamlined, and included in the fast-swimming fish (Sayuti et al. 2022). The *kawakawa*'s body shape helps the fish swim more efficiently, nimbly, and quickly in seawater. *Kawakawa* is a carnivorous fish (Pebiloka et al. 2023). Morphologically, *kawakawa* have unique characteristics: oblique and curved black stripes above the ribs. Dark spots are as many as 2 to 5 above the ventral fin (Mardlijah et al. 2022), and black stripes between the abdomen and fins (Pulungan et al. 2022).

Kawakawa has one pair of pectoral fins, one pair of ventral fins, one anal fin, one caudal fin, and two dorsal fins. *Kawakawa* has two dorsal fins spaced apart (Isti'anah and Maulana 2020). Spines support the spaced first dorsal fin, and soft fingers only support the second dorsal fin (Ahmed et al. 2015). The anal fin has 14 weak fingers, and there are 6 to 9 additional fingers; 8 to 10 pieces of small fins located behind the second dorsal fin (Nuraisyah et al. 2019). Weak fingers in fish have internodes, are generally branched, and bend easily to move (Kahby 2023). *Kawakawa* has 10 to 14 anal fins to help the fish to swim backward by pushing the anal fin down so that they can push the water in the opposite direction and moves backward. In the abdomen, *kawakawa* has two lobes (interpelvic process) (Hidayat et al. 2018).

Kawakawa has a tapered, slender, elongated head shape. The head shape of the *kawakawa* helps the *kawakawa* to cut through the water while swimming at a reasonably high speed. *Kawakawa* have a broad mouth type and tilt down; their scales are tiny and belong to the ctenoid type. Ctenoid scales have small serrations on their posterior parts; these scales are thinner, smaller, lighter, and transparent (Valen et al. 2022). On the tail, there are three "keels" or serrations with a sharp central peak; the keel in the middle is elongated and higher than the keel that squeezes it. The swimming mechanism of *kawakawa* is like that of tuna, but *kawakawa* do not have swim bladders and are different from tuna, which have red muscle distribution (Havelka et al. 2021). The swim bubble is a bag that contains air or oxygen and is in the body cavity of some fish (Fikri et al. 2023).

Kawakawa has a black, turquoise, or metallic gray color on the back with smooth color gradations. The color helps *kawakawa* camouflage in seawater. *Kawakawa* has a silvery white color on the abdomen, and the silver color is brighter and shiny than the greenish-blue color on the back of the *kawakawa* (Hamed et al. 2016). The forehead of the *kawakawa* is dark blue or dark green, with tiny black dots. The dorsal fin also has a dark blue or dark green color, and the tip of the dorsal fin is black. The silver color on the belly of the *kawakawa* helps the fish to reflect light and avoid predators from below. The body color of the dark dorsal and bright ventral parts is called countershading, as the effort to camouflage in the open seas (Kaidi et al. 2021).

The eyes of *kawakawa* have a diameter ranging from 5-7 mm and a dark blue iris and black pupils. *Kawakawa* have a dorso temporal direction of vision or upper forward vision, which benefits fish; they quickly see prey on the water and see predators from above and below to help escape predators. The dorso-temporal direction of the eyes also serves to navigate their environment. *Kawakawa* has receptor cells composed of single-cone and double-cone cells that spread evenly throughout the retina. Single-cone and double-cone cells make *kawakawa* vision highly sensitive to differences in color and light intensity received (Fiolita et al. 2017). The presence of double-cone cells allows fish to perceive better colors and be more diverse.

The skeleton is a structure that helps the body stand upright, serves as a lifeguard, and supports the body's organs. Based on X-ray photography, the bone morphology of *kawakawa* consists of 20 segments of the trunk and 18 segments of the tail (Shengjie et al. 2022). *Kawakawa* have a light and strong bone skeleton that allows them to swim quickly and nimbly in the water. *Kawakawa* has gill bones on the head's sides and supports large pectoral fins. *Kawakawa* has 29 to 33 gills in the first hollow and 28 or 29 Gill teeth, while vomerine teeth are absent.

Fish morphometrics are characteristics related to body size or body parts of fish (Figure 2), such as total length and length of fish body poles (Radona et al. 2017). *Kawakawa* has the characteristics of a medium-sized body. The growth in terms of body length significantly affects weight, most likely caused by two factors: the availability of food sources and the body shape of fish (Lelono and Bintoro 2019). *Kawakawa* can grow up to a maximum weight of 14 kg and a maximum Fork Length (FL) of 100 cm (Ohshimo et al. 2024). Generally, the caught *kawakawa* weigh less than half that size in most of their distribution area. Male and female *kawakawa* have different lengths and weights; males are generally larger than females (Lestari and Suparno 2023). The difference in size between males and females occurs due to differences in behavior, mortality, and growth rates (Setiawati and Suparno 2023). FL is measured starting from the mouth to the tail pole of the fish (Horton et al. 2018). Fork length measurements can identify species, estimate age, and monitor population health and growth patterns.

The fish caught in the Java Sea have a fork length of 27-58 cm (Masuswo and Widodo 2016), while those in western Sumatra have a fork length of 30-60 cm (Fathurriadi 2020). The fork length of *kawakawa* caught in Pati waters ranged from 33-52 cm (Prasetyo et al. 2019), in the Sunda Strait was 40.7 cm (Ardelia et al. 2016), and in the Malacca Strait was 43 cm (Jamon et al. 2016). The difference in the fork length of *kawakawa* in various waters can be caused by differences in aquatic environmental conditions (Ekawaty and Jatmiko 2018). The differences in the fork length of *kawakawa* could be caused by differences in fishing gear during fishing, ecological conditions, and variations in fishing intensity (Chodrijah et al. 2016). Analyzing the length and weight of *kawakawa* is critical to determining the biological condition of fish and fish stocks, making it easier to manage the sustainability of fish biodiversity. In fisheries biology, the relationship between the length and weight of fish is needed for complementary information data (Arnenda et al. 2020). Research on the relationship between the length and weight of fish helps to understand their habitat, reproductive behavior, history, life cycle, and fish health (Mudumala et al. 2018).

NUTRITIONAL VALUE OF *KAWAKAWA* (*Euthynnus affinis*)

Fishery resources are vital for human due to their commercial value and high nutritional content (Cahyono et al. 2023). *Kawakawa* is a species of mackerel tuna found in the western and Indian Pacific Oceans. It is widely distributed and abundant. This fish is usually caught as a bycatch in commercial fishing. The fish is traded in various forms worldwide (Ahmed and Bat 2015), and canned tuna is one of the most consumed seafood worldwide (Garofalo et al. 2023). *Kawakawa* is included in the fish that are sold freely or commercialized. Due to the increasing demand for canned tuna, the fishing industry is concentrated in Asia, particularly Japan, Taiwan, China, Indonesia, and South Korea (Abinaya and Sajeevan 2023). Nonetheless, *kawakawa* viscera can be used as a source of protease enzymes (Taheri and Bakhshizadeh 2020).

At zero hour, *kawakawa* chips had the moisture 70.95±0.42%, protein 1.920±0.21%, lipids 0.45±0.22, and ash contents 2.61±0.07 on wet weight respectively (Abou-Taleb et al. 2019). The tiny tuna, *kawakawa*, and carp fish chips had pH, TVBN (Total Volatile Basic Nitrogen), TMA (Trimethylamine), and TBA (Thiobarbutic Acid) values of (6.07±0.04, 0.008, 0.009, 0.005 mg MDA/kg), (6.44±0.09, 0.008, 6.44, 6.07), and (6.16±0.09, 11.38, 39.04, 43.94 mg/100g), respectively, at zero time (Abou-Taleb et al. 2019).

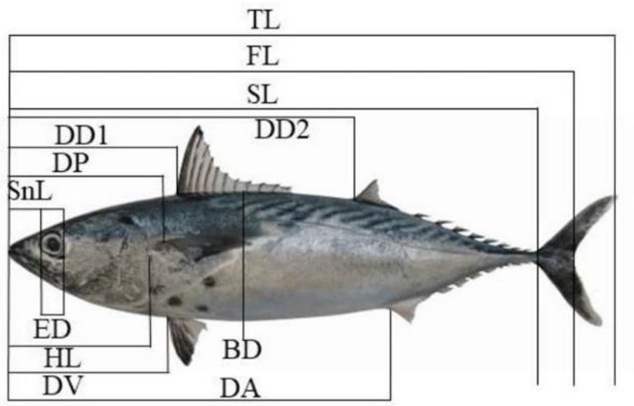

Figure 2. Morphometric measurements of *Euthynnus affinis* (*Kawakawa*). TL: Total Length, FL: Fork Length, SL: Standard Length, HL: Head Length, BD: Body Depth, ED: Eye Diameter, SnL: Snout Length, DP: Distance of pectoral fin, DD1: Distance of the first dorsal fin, DD2: Distance of the second dorsal fin, DV: Distance of ventral fin, DA: Distance of anal fin. Source: Binashikhbubkr et al. (2024).

The nutritional value of protein is determined by its amino acid composition (score), the level of essential amino acids, and digestibility (FAO 2013; Bandyopadhyay et al. 2022). Fish protein is superior to red meat due to its lower collagen content and better digestion (>90%) (Vijaykrishnaraj and Prabhasankar 2015). Fish consumption has several health benefits due to its high content of omega-3 polyunsaturated fatty acids (PUFAs) (Tilami et al. 2018). *Kawakawa* is an excellent source of nutrients due to its high and low fat and protein content. Ahmed and Bat (2015) stated that *kawakawa* contains high iron and low lead in the liver and muscle. Fish liver has substantially higher iron levels than muscle tissue since it plays a physiological role in the production of blood. Previous findings showed the health benefits of food-derived bioactive peptides and proteins. These dietary proteins break down easily to release more potent soluble peptides against heat, stomach acid, and proteolytic enzymes. Protein hydrolysates have excellent biological activities, including antihypertensive, antioxidant, antibacterial, immunomodulatory, and anticancer (Vijaykrishnaraj and Prabhasankar 2015). Since they are higher in the food chain than other fish, top predators like *kawakawa* collect heavy metals. In polluted and contaminated water, they are continuously exposed to contaminants. According to Ahmed and Bat (2015), muscle fibers of the *kawakawa* contained Fe (46.9644±12.54456 μg/g) and Mn (10.4089±3.19444 μg/g). The liver contained Ni (2.7983±0.0.81944 μg/g), Fe (660.2367±141.23909 μg/g), and Mn (47.3711±12.29087 μg/g). However, this fish contained hazardous metals such as Pb and Ni. Hazardous or heavy metals should not be found or detected in food intended for human consumption. Based on the European Union Regulation, Pb is a hazardous metal. Pb concentration in the muscle and liver of *kawakawa* was 0.4958±0.13641 μg/g and 1.5950±0.3045 μg/g, respectively (Ahmed and Bat 2015). These values were much higher than the maximum level (0.30 mg/kg wet weight) established by the Turkish Food Codex and the EC (Commission Regulation). It should be noted that Pb levels in *kawakawa* were expressed in μg metal g-ı dry weight in the present study. It makes it very difficult to compare the two (Ahmed and Bat 2015). However, Ahmed and Bat (2015) also stated that *kawakawa* from the area is generally safe for human consumption, and several metals were found in *kawakawa* samples at varying levels but within the maximum residual levels allowed by the EU and FAO/WHO. The metal concentrations were higher in the liver than in the muscle, but *kawakawa* livers are not eaten.

The kawakawa condition variable, which assesses the physical ability to survive and reproduce, shows that the fish thrives in a healthy habitat and contains important nutrients. Water quality, environmental stressors, and food availability are just a few of the variables that impact various aspects of fish health. It's fascinating to see that fish with a high condition factor are not just healthy but also remarkably adaptable to their environment, thriving in even the most challenging conditions.

The fat content of *kawakawa* is 0.87%, which is lower than that of other fish species, such as big-head hairtail fish. Because of its low-fat content, it is a good choice for those who wish to eat less fat without compromising nutrients. In contrast, tuna, including *kawakawa*, has a protein content ranging from 20 to 25%, making it an excellent protein source. *Kawakawa* is also an ingredient in the fish oil production process. Many impurities, including free fatty acids, pigments, phosphates, and particulate debris, are contained in the extracted crude fish oil (Hetta et al. 2020). White-muscle and dark-muscle tuna have excellent nutritional content, texture, and quality, making them ideal for culinary purposes (Kannaiyan et al. 2019). It is an excellent choice for anyone to increase protein consumption due to its high protein content, especially for athletes or people who exercise frequently.

Fish proteins, peptides, and amino acids have recently attracted attention because they exhibit characteristics comparable to PUFAs (Mohanty et al. 2019). In addition, omega-3 fatty acids, essential for the proper functioning of many organs in the body and have many health benefits, are abundant in *kawakawa*. Fish is also a good source of essential minerals, such as copper (Cu), manganese (Mn), zinc (Zn), and selenium (Se), which play a vital role in many biological processes (Khalili and Sampels 2018). Tuna oil has a long chain of unsaturated fatty acids, omega-3 and omega-6, especially DHA, which can lower the risk of various diseases (Ferdosh et al. 2015). The *kawakawa* diet consists of different types of fish, crabs, and mollusks, which impacts the nutritional value of fish. This diversified diet increases the nutritional value of fish because it enables them to absorb a wide range of elements from their dietary sources. Due to its high protein, low fat, and high omega-3 content, *kawakawa* has good nutritional value overall. The excellent nutritional value of *kawakawa* is also due to its varied diet and ideal environmental conditions.

BENEFITS OF *KAWAKAWA* (*Euthynnus affinis*) FOR HUMAN HEALTH

As explained, *kawakawa* has a high nutritional value that supports human health. The nutritional content of *kawakawa* can prevent various diseases, including heart disease and cancer (Fadzilla 2018). Although *kawakawa* has not been processed into pills or medical drugs, many of its ingredients support human health (Taheri and Bakhshizadeh 2020). These fish are often used for a healthy diet to support the health of the heart, brain, and immune system; with a high protein content, it reaches about 26.6%, making it an excellent source of protein (Abou-Taleb et al. 2022). Protein is an essential component in the diet because it plays a role in building and repairing body tissues and supporting various biological functions. The high protein content in *kawakawa* makes it very beneficial for muscle growth and maintenance and supports a healthy immune system.

In addition, many processed foods currently use *kawakawa* as a primary ingredient, ranging from canned food, nuggets, and various other products, so that the consumption of *kawakawa* becomes more manageable for children to adults (Kartikaningsih et al. 2021) and enjoyable different levels of society, so it increased health benefits. Some health benefits of consuming *kawakawa* include improving heart health through omega-3 content that can lower harmful cholesterol levels and the risk of cardiovascular disease. In addition, this fish's selenium content is an antioxidant that protects the body's cells from oxidative damage and supports healthy thyroid function. With its wide range of health benefits, *kawakawa* is an excellent food choice to support overall health and improve quality of life. As for some of the health benefits of *kawakawa* consumption, among others:

Prevent stunting

Stunting is one of the health problems that must be eradicated today (Sriwijayanti and Devi 2020). Various efforts are made to prevent stunting, including fulfilling nutrition when the fetus is still in the womb and newborn. Stunting is a growth and development failure in infants due to insufficient macronutrients such as protein and microelements such as vitamin D (Widanti 2016). Stunting can also be said to be a condition in which a person's height is shorter than other people's height in general (Simamora et al. 2019). According to Putri (2023), *kawakawa*, which is rich in omega-3 fatty acids, is undoubtedly well consumed by children in the growth phase. Omega 3 can help improve cognition, concentration, and memory. Omega-3 is excellent for brain cell development during the growth and development phase (Nurasmi 2021). *Kawakawa* contains omega-6, which is necessary in addition to omega-3 to avoid stunting and malnutrition (Ningsih et al. 2024). In a study by Nurfaidah et al. (2024), omega-3 was added to the solid food of breast milk substitute for nutritional fulfillment to prevent stunting. According to Wardhana (2024), omega-3 and omega-6 help to increase brain intelligence and avoid blood clots. Being deficient in omega-3 and omega-6 can increase the potential for stunting in children.

Prevent cancer

Consuming *kawakawa* can prevent cancer (Kannaiyan et al. 2019) due to its selenium content (Sa'adah 2022). Consumption of high-selenium foods can prevent the growth of cancer cells (Razaghi et al. 2021). Selenium is an antidote to free radicals that cause cancer. According to research in the 2000s by the American Institute for Cancer Research (AICR), selenium can aid in the prevention of lung and skin cancer. *Kawakawa* also has sufficient vitamin D, which regulates cell growth and reduces cancer risk by controlling cell differentiation and proliferation (Andhikawati et al. 2021). According to Paelongan et al. (2022), vitamin D induces apoptosis of cancer cells and plays an important and promising role in cancer therapy. The nutrients of *kawakawa*, such as selenium and vitamin D, significantly affect cancer prevention. Thus, consuming *kawakawa* can be an important part of a healthy diet to prevent various types of cancer.

Reduces heart risk

Heart disease is one of the diseases with a high mortality rate (Utomo and Mesran 2020). Omega-3 reduces the risk of heart attack (Bahurmiz 2019), and omega-3 is easily found in marine fish (Shen et al 2022). Omega-3s can prevent heart attacks. The omega-3 is the polyunsaturated fatty acids DHA and EPA (Djuricic and Calder 2021). The DHA also helps reduce the risk of developing heart disease (Yamagata 2020). Laidlaw and Tanya (2019) reported that consuming omega-3 can reduce cholesterol, ultimately reducing the risk of heart disease. Fish is the best source of DHA. In addition, DHA can also reduce the level of triglycerides in the blood, where triglycerides are a significant factor in the occurrence of heart disease (Setiawan and Halim 2022). In addition to DHA, EPA can also prevent degenerative diseases in the fetus and adults, and the fetus needs EPA to form the heart (Sari 2022). According to Danitasari and Rahmawaty (2024), *kawakawa* has the highest DHA and EPA content compared to some fish in Indonesia, such as red snapper (*Lutjanus campechanus*), white pomfret (*Pampus argenteus*), selar fish (*Selaroides leptolepis*), and mackerel (*Scomberomorus* sp.).

Maintain eye health

kawakawa has a relatively high DHA (decosahexaenoic acid) (Andhikawati 2020). DHA is one type of omega-3 that is essential for the body, especially for brain and eye health (Sugasini et al. 2020). DHA can help prevent macular degeneration and dry eye syndrome. In addition, the content of DHA can also help reduce inflammation in the eyes, which can cause damage to the lens and eye tissue. DHA can help maintain the function of the sense of sight. In addition, adequate DHA intake during pregnancy will be perfect for children's vision development (Kasmara et al. 2023). According to Qardhawijayanti (2022), DHA is one of the important constituent components of the eye's retina. The retina is one of the eye layers that captures light and sends visual signals to the brain. In the eye, DHA accumulates in the photoreceptor cells. High DHA content in photoreceptor cells influences how sharp the eye's visual is.

Improve immunity

According to Nalawati et al. (2024), *kawakawa* has various nutritional contents that are very beneficial for health, such as magnesium, iron, omega-3, omega-6, and selenium. These ingredients play an essential role in improving immunity. Its high nutritional and protein content makes it a highly recommended food. The omega-3 can increase the body's immunity. Omega-3s can help reduce inflammation and improve the immune response so that the body becomes better against infection and disease. According to Nolitriani et al. (2020), selenium is a vital selenocysteine component in cell function and biochemistry. Therefore, selenium can affect the body's specific and non-specific immune systems. Selenium could be an antiviral, antioxidant, and thyroid hormone regulator.

Prevent anemia

Kawakawa contains a natural iron. Iron is one of the essential minerals for various vital functions. Iron can help prevent anemia. Anemia is a lack of red blood cell formation and can be overcome by consuming iron. Gardiarini et al. (2021) state that adequately processed iron-rich foods can help prevent anemia. Consumption of foods high in iron, such as *kawakawa*, helps increase iron levels, supporting the production of red blood cells. Iron content in *kawakawa* helps the body produce blood cells. Fish consumption can prevent various diseases, including anemia. It suggests that *kawakawa*, with high iron content, prevents anemia.

Maintaining bone health

Oviana et al. (2019) stated that *kawakawa* has a reasonably high vitamin D. Vitamin D is an essential nutrient even in fetal development. Vitamin D is vital in forming and strengthening fetal bones (Shita and Sulistyawati 2015). Vitamin D is an essential micronutrient that helps maintain bone health. According to Fazalina et al. (2021), vitamin D deficiency results in vulnerable bones that break easily. Vitamin D deficiency causes the body not to absorb calcium efficiently, resulting in brittle and weak bones. Consuming *kawakawa*, which is rich in vitamin D, will be an effective solution to meet daily vitamin D requirements.

Secondary metabolites

The efficacy of *kawakawa* is related to its secondary metabolites. According to Hanifa et al. (2019), secondary metabolites are compounds only owned by specific organisms that are very valuable for pharmaceuticals, such as raw materials for drugs or other health. Marine animals generally do not have a perfect secretion system like mammals. It causes marine organisms to have very diverse chemical compounds, especially secondary metabolites. There are several types of secondary metabolites contained in *kawakawa*, including:

Carotenoids

Carotenoids are secondary metabolites produced by organisms living under extreme biotic and abiotic conditions (Ayala-Meza et al. 2022). According to Putra et al. (2023), carotenoids are natural pigments that can be found in animals. Carotenoids are pigments that provide color in fish. In *kawakawa*, the primary type of carotenoid is the astaxanthin type, which gives a red color to fish meat. The health benefits of carotenoids include protecting cells from oxidative damage, improving immune system function, and helping the body fight infection and disease. They may help reduce the risk of age-related macular degeneration.

Steroids

Steroids are bioactive compounds classified as non-polar (Prayitno et al. 2021). In tuna, steroids play an important role in various biological and physiological functions. Steroids have several bioactivities, such as anti-cancer drugs.

Alkaloids

Kawakawa positively contains alkaloids in its flesh (Hafiludin 2011). Alkaloids are the most secondary metabolite compounds that have nitrogen atoms. Alkaloids are derivatives of amino acids that have a bitter taste. Alkaloids play an important role in an organism's natural defenses, helping to protect against pathogens such as bacteria, viruses, and fungi. Alkaloids are known for their significant range of biological activities, including antimicrobial, anticancer, and antioxidant activities (Adamski et al. 2020).

Kawakawa will have good health benefits in natural conditions and not be contaminated (Kusumaningsih 2020). The excellent nutritional content of *kawakawa* provides various health benefits. It is necessary to ensure that this fish comes from a safe place to ensure its quality. Proper processing can also maintain nutrient content (Robert et al. 2022). In this case, environmental aspects and the management or cultivation of *kawakawa* are important in keeping nutrients excellent and ensuring that the fish does not contain toxic metals. Aquaculture conducted in a controlled environment could reduce the risk of contamination from chemicals. The balanced consumption and good quality of *kawakawa* could benefit consumers significantly. Therefore, understanding the selection and processing is needed for good consumption to obtain the maximum benefits of consuming *kawakawa*. With its rich nutritional content, including protein, omega-3 fatty acids, vitamins, and minerals, tuna can improve heart health, support brain function, strengthen the immune system, and reduce the risk of various chronic diseases. *Kawakawa* in the daily diet provides several nutritional benefits and supports a healthy and balanced lifestyle. Researchers and health practitioners should encourage people to increase tuna consumption to maintain health and prevent diseases. In this way, we can maximize the nutritional potential of tuna fish for long-term well-being and health.

CONCLUDING REMARKS

The review on *kawakawa* (*E. affinis*) aims to provide an understanding of the habitat, morphological characteristics, nutritional content, and benefits of *kawakawa* for health. *Kawakawa* is a species of pelagic fish of the Scombridae family that has a vast habitat and distribution in tropical and subtropical waters in the Indo-Pacific region. *Kawakawa* has unique morphological characteristics: oblique and curved black stripes on the ribs, dark spots as much as 2 to 5 above the ventral fins, and black stripes between the abdomen and fins. The body shape of the *kawakawa* is elongated and slender, like a torpedo. As a pelagic fish, the *kawakawa* has a line shape on its body that allows it to move in the waters without experiencing any obstacles. *Kawakawa* has 20-25% protein, low fat, and high omega-3. The nutritional content in *kawakawa* can be beneficial for health, preventing stunting, improving brain intelligence, preventing blood clots, and increasing immunity. Omega-3 content in *kawakawa* can also lower cholesterol if consumed regularly. The selenium and vitamin D content in *kawakawa* is very influential in cancer prevention and maintaining bone health. *Kawakawa* contains DHA, which can help lower the risk of heart attack, improve the eye's health, and reduce inflammation in the eye that can cause damage to the lens and eye tissue. The iron content in *kawakawa* can prevent anemia. *Kawakawa* has a high nutritional value, making it an excellent food choice. The habitat or place of cultivation of *kawakawa* can affect its nutritional content. Therefore, it is necessary to ensure that this fish comes from a safe place to ensure its quality.

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INDO PAC J OCEAN LIFE
Volume 8, Number 2, December 2024
Pages: 84-93

P-ISSN: 2775-1961
E-ISSN: 2775-1953
DOI: 10.13057/oceanlife/o080203

Species diversity of mangrove at tree and pole level in Sampang and Pamekasan Districts, Madura Island, Indonesia

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Manuscript received: 31 December 2023. Revision accepted: 14 November 2024.

Abstract. *Lathifah MN, Muazulfa TI, Nisa WK, Raharjo YAA, Arta YPA, Setyawan AD. 2024. Species diversity of mangrove at tree and pole level in Sampang and Pamekasan Districts, Madura Island, Indonesia. Indo Pac J Ocean Life 8: 84-93.* Madura Island, Indonesia, located northeast of Java Island, features naturally occurring mangrove vegetation along its coastline. Mangrove forests encompass approximately 75% of the coastlines in tropical and subtropical regions. The diversity of mangrove species needs to be assessed to determine the current situation and provide an evaluation of biodiversity conservation. In this research, the mangrove species diversity at both tree and pole level in the coast of Taddan Village, Sampang District (7°13'7.53"S, 113°16'15.93"E), Song Osong Beach, Sampang District (7°13'19.55"S, 113°12'10.63"E), Branta Tinggi Village, Pamekasan District (7°13'19.53"S, 113°27'12.45"E) and Tlanakan Village, Pamekasan District (7°13'16.24"S, 113°26'11.68"E), Madura Island, East Java, Indonesia were determined. A 150 m long transect plot was established at each station, yielding 40 plots for 4 stations. Abiotic factors, including temperature, salinity, pH, and soil moisture at the study location, were also measured. The Shannon-Wiener Index (H') is used to analyze the species diversity index; Pielou's Evenness and Margalef's Richness index analysis are also calculated in this research. The results indicated that there are 3 species consisting of *Rhizophora stylosa, Avicennia marina,* and *Sonneratia alba.* The diversity analysis showed a moderate category (H' range: 1.85-2.56), with the highest values at both tree and pole levels recorded at Song Osong Beach (H' tree: 2.56, H' pole: 2.19). Meanwhile, the lowest value at the tree level was recorded at Taddan Village (H': 1.99), and the pole level is at Branta Tinggi Village (H': 1.85). The Margalef's richness values obtained range from D: 39.34-95.58 (high) at the tree level and D: 13.61-98.00 (high) at the pole level. The results of Pielou's evenness calculations indicate low evenness at all stations (J' tree: 0.05-0.27: J' pole: 0.02-0.48. In an ecosystem with a medium-level diversity index, vegetation can grow with sufficient support but also faces significant threats. In this instance, the threats arise from anthropogenic activities, such as illegal logging and land conversion for aquaculture purposes. The implementation of mangrove maintenance efforts can be achieved through protection and rehabilitation initiatives that collaborate with local governments and engage indigenous communities.

Keywords: Diversity index, Madura Island, mangrove, Shannon-Wiener Index

Abbreviations: DBH: Diameter at Breast Height

INTRODUCTION

Mangrove forests encompass approximately 75% of the coastline in tropical and subtropical regions. Indonesia is the habitat of almost 30% of the total mangrove area in the world. Until 2014, Indonesia was recorded as a country with the world's largest mangrove forest (Hamilton and Casey 2016). Mangrove forests protect coastal areas from abrasion, wind, storms, and other natural disasters (Rafael and Calumpong 2018). Mangrove trees can adapt to strong waves and high salinity (Amalia et al. 2016). Various types of mangrove species have diverse ways of adapting to various types of soil and geographical location. Thus, mangrove communities have different vegetation zones (Mojiol and Salleh 2017). Mangrove forests have a variety of plant species, but what dominates are some trees and shrubs that can absorb carbon and are resistant to high salinity (Afifudin 2019). Several factors affect mangrove forest species structure and characteristics, such as climate, tidal wave distance, coastal landform, soil type, and freshwater availability (Koswara et al. 2017). Therefore, to adapt to extreme environments, mangroves exhibit both morphological and physiological adaptations. Notably, these species possess unique mechanisms, including the adjustment of salt glands in their leaves for salt excretion and respiratory roots to assist respiration in oxygen-poor sediment conditions (Maiti and Chowduri 2013).

Species diversity indicates the different types of organisms that live in an area, which includes variations in genetics, species, and ecosystems. Species diversity is necessary to measure and evaluate biodiversity conservation (Morris et al. 2014). Species diversity is measured using a mathematical function in general (Daly et al. 2018), referred to as the species diversity index. The diversity index is used to compare different communities in an area, especially to observe the impact of disturbances on the community (Rochmady 2015). The high level of mangrove species diversity is valuable and must be maintained (Nawar et al. 2021).

Madura Island is one of the islands in East Java Province, Indonesia. This island is located in the northeastern part of Java Island, separated from Java by the Madura Strait. Geographically, Madura is located between 6°00'-7°10' south latitude and 113°15'-114°20' east longitude. Madura Island has mangrove vegetation along its coast and has a coastline of about 985 km, but this may change due to the influence of coastal accretion (Sukandar et al. 2016; Agustin and Achmad 2020). Mangrove vegetation occupies various types of land and water areas, known as 'geomorphologies'. These include mudflats, estuaries, and riverbanks. The mangrove forests on Madura Island are forests that form naturally. According to Rosadi et al. (2018), two types of mangroves dominate the Sampang District area, Madura, namely *Rhizophora apiculata* and *Sonneratia alba*. The density of vegetation in mangrove forests in Sampang District is relatively dense and has trees that are not too tall. Mangrove ecosystems in the Sampang District can generally be found in coastal areas that form a green belt (Rosadi et al. 2018). The research focuses on the Sampang and Pamekasan Districts, as both areas are situated in the southern coastal region traversed by the Jalan Lintas Selatan (Southern Cross Road). This road frequently experiences tidal flooding; therefore, the study aims to evaluate the presence of mangroves in these areas. Additionally, the results are expected to offer insights into the potential for reforestation efforts to mitigate the impact of tidal floods. Based on the description above, it is important to know the diversity of mangroves to support the sustainability of mangrove ecosystems. This study aims to determine the diversity of mangrove species at the tree and pole level on the coast of Sampang and Pamekasan Districts, Madura Island, Indonesia.

MATERIALS AND METHODS

Study area

This research was conducted from 9 to 10 December 2023 in Sampang and Pamekasan Districts located on Madura Island, East Java, Indonesia (Figures 1 and 2). Based on BMKG station data, Madura Island has an annual rainfall of 1,314.67 mm with an average monthly air temperature of 27.9°C and an average length of solar radiation of 2149,673 hours/year (Latifah and Siregar 2021). Sampang District is located at coordinates 6°05'-7°13'S and 113°08'-113°39'E, while Pamekasan District is located at coordinates 6°51'-7°31' S and 113°19'-113°58' E. There are 4 sampling points for mangrove diversity on the Sampang and Pamekasan coasts: Taddan Village (Station 1), Tlanakan Village (Station 2), Branta Tinggi Village (Station 3), and Song Osong Beach (Station 4). The coordinates of each sampling point and the differences in substrate characteristics in the four study areas can be seen in Table 1.

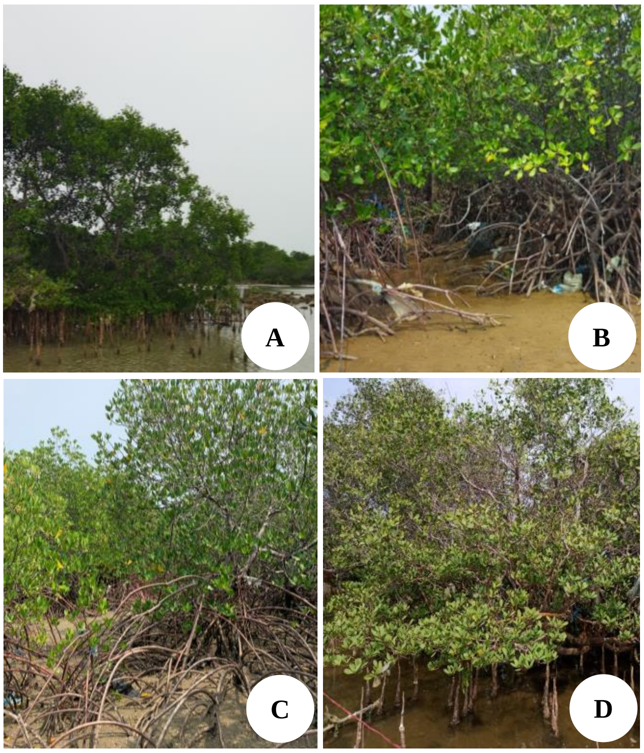

Figure 1. Mangrove ecosystem in Madura Island, East Java, Indonesia: A. Song Osong Beach, B. Taddan Village, C. Tlanakan Village, and D. Branta Tinggi Village

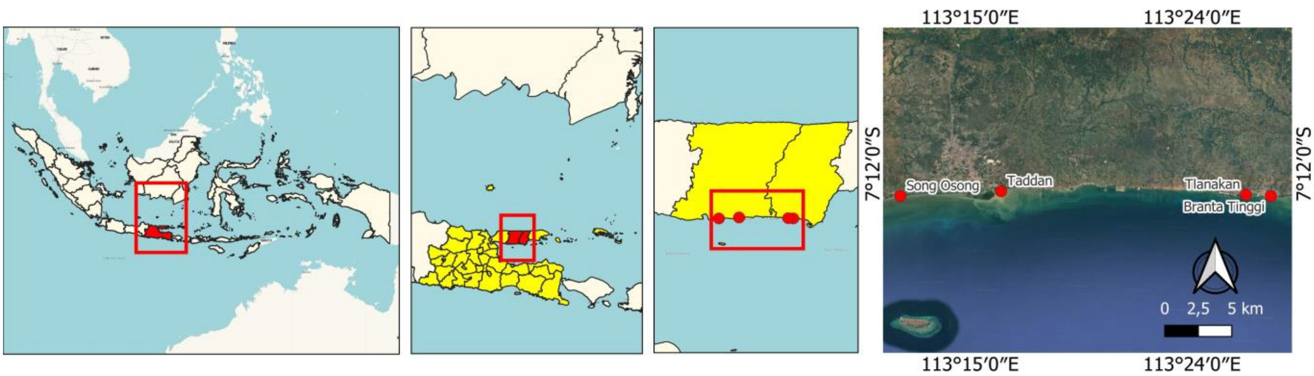

Figure 2. Location of 4 mangrove diversity sampling points: Song Osong Beach, Taddan Village, Tlanakan Village, and Branta Tinggi Village of Madura Island, East Java, Indonesia

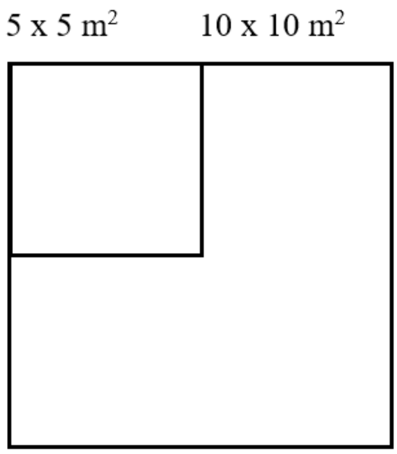

Figure 3. Square plot quadrate for sampling mangrove stand

Procedures

Mangrove sampling was conducted at 4 research stations with ten square plots of 10×10 m^2 size at each station for tree species identification and 5×5 m^2 for pole type identification (Figure 3). This methodology, in accordance with Sholiqin et al. (2021), builds on their use of three-square plot sizes for sampling at the seedling, pole, and tree levels. We have refined this approach, using only two square plot sizes were used to sample mangroves at the pole and tree levels following the predetermined research objectives. The mangrove stand is categorized as plants when the diameter is above 20 cm and is included in the category of plants with a Diameter at Breast Height (DBH) of 10-20 cm (Wijana et al. 2022). Observations include identifying the type of mangrove species in a square plot and counting the total number of species of each mangrove stand (trees and poles), considering the height and diameter of plants following Sholiqin et al. (2021).

At each observation station, measurements were also made on several abiotic factors with three repetitions. Abiotic factors measured include temperature, salinity, pH, and soil moisture. Rainfall and air temperature data were obtained through BMKG data. Abiotic factor measurements were carried out thrice in the morning until noon in each research station to verify the repeatability of measurement results (Yu et al. 2014). Samples of unidentified species were identified by analyzing photographs of samples. Key morphological characters used for the identification of mangrove plants were leaf shape, flower color, and fruit (Dahibhate et al. 2020; Mwakha et al. 2020).

Data analysis

Mangrove diversity was calculated using the Shannon-Wiener index (H') (Asuk et al. 2018; Suwanto et al. 2021).

$$H' = -\sum Pi \ln Pi$$

$$Pi = \frac{ni}{N}$$

Where:

H': Shannon-Wiener Diversity Index

Pi: Number of individuals of a species divided by the total number of species found.

H' values range from 0 (low diversity) to 1 (high diversity). The criteria for the diversity index are as follows: (i) H'<1.5: low diversity; (ii) 1.5≤H'≤3.5: moderate diversity; (iii) H'>3.5: high diversity (Krebs 1989).

The Index of Evennes was determined using Pielou's (J) (Heip et al. 1998)

$$J' = \frac{H'}{H'max}$$

$$H' \max = -\sum_{i=1}^{S} S^2 \ln \frac{1}{S} = \ln S$$

Where:

J': Pielou’s Evenness Index

H': Shannon-Wiener Diversity Index

H'max: Maximum Shannon-Wiener Diversity Index

S: Number of species.

The value of J ranges from 0 to 1. A value closer to 1 indicates a higher level of evenness.

For the species richness index, the Margalef Index (D) was used (Subhan et al. 2021)

$$D = \frac{S - 1}{\ln N}$$

Where:

D: Margalef Richness Index

S: Number of species present in the community

N: Number of individuals in the community.

The criteria for the richness index are as follows: (i) D<3.5: low species richness; (ii) 3.5<D<5: moderate species richness; (iv) D>5: high species richness.

Data analysis was performed quantitatively using Microsoft Office Excel software.

RESULT AND DISCUSSION

Environment condition of study area

The observations result from four points have varied soil types: Taddan has muddy, quite thick type of soil; Tlanakan and Branta Tinggi have muddy and sandy soil; Song Osong Beach has a sandy type of soil. The results of measurements and observations can be seen in Table 1. Measurement of abiotic factors in mangrove ecosystems was also carried out in the research of Irsadi et al. (2019) in the coastal area of Semarang-Demak in 2018 to determine the environmental factors supporting mangrove ecosystems. Abiotic factors measured in Irsadi et al. (2019) research include salinity, air temperature, water pH, soil pH, rainfall, and light intensity. In his research, salinity, water pH, soil pH, and light intensity were observed directly in the field.

Table 1. Abiotic factors measured at 4 sampling points

Location/Station	Soil temp. (°C)	Water temp. (°C)	Air temp. (°C)	Soil pH	Water pH	Salinity (ppt)	Soil moisture (θ)	Substrate characteristics
Taddan/1 (7°13'7.53"S, 113°16'15.93"E)	30.34±0.72	30.67±0.72	31.70±0.57	6.170±0.62	7.60±0.05	28.30±1.36	>10	Muddy
Branta Tinggi/2 (7°13'19.53"S, 113°27'12.45"E)	34.30±0.58	34.30±0.75	37.17±0.59	6.80±0.08	7.37±0.03	28.30±1.36	>10	Muddy, Sandy
Tlanakan/3 (7°13'16.24"S, 113°26'11.68"E)	35.00±0.00	36.00±0.47	36.30±0.33	7.10±0.08	8.03±0.15	32.67±0.98	>10	Muddy, Sandy
Song Osong/4 (7°13'19.55"S, 113°12'10.63"E)	34.70±0.33	35.70±0.75	36.30±0.33	6.97±0.03	7.53±0.07	19.67±1.19	>10	Sandy

Note: Temp.: Temperature

The soil temperature measured in this study ranged from 30.34°C to 35.00°C. Increasing soil temperature can stimulate microflora metabolic activities to accelerate the pace of the mineralization process (Efendi et al. 2018). Soil pH ranged from 6.17 to 7.10, which is suitable for mangrove growth. Based on Badu et al. (2022), the soil pH for mangrove sediment ranges from 6 to 7. All four sampling sites have a humidity of more than 10 on soil moisture parameters. High soil moisture also affects germination rates (Hidayah et al. 2022).

Water temperature ranged from 30.67°C to 36.00°C. This variation is influenced by several factors, such as the differences in the intensity of sunlight hitting the water, and several factors, such as the geographical location of the waters, circulation of ocean currents, wind, and seasons (Widiawati et al. 2023). Metabolic activity and geographical distribution of aquatic organisms are much influenced by water temperature (Dallas and Ross-Gillespie 2015). Water pH in this study ranged from 7.37 to 8.03. The pH value of water in the Sampang and Pamekasan coastal areas is still following the threshold of seawater quality standards based on Kepmen LH No. 51 of 2004 for biota health in the range of normal limits up to a pH value of 8.5 (Widiawati et al. 2023). Salinity ranged from 19.67 ppt to 32.67 ppt. Mangrove can grow well with salinity levels of 10-30 ppt (Khawarizmi et al. 2021). In addition, the salinity levels in Tlanakan village exceed the optimal salinity levels but can still be tolerated.

The air temperature ranged from 31.70°C to 37.17°C. The temperature at 4 mangrove observation points on the Sampang and Pamekasan coasts is quite high. This condition is still conducive for mangrove growth, as mangroves thrive at temperatures ranging from 4.5°C to 36°C (Hidayah et al. 2022), unless Branta Tinggi was recorded at 37.17°C. However, this does not significantly affect mangrove growth. According to Asbridge et al. (2015), species that grow near the equator exhibit greater tolerance to air temperatures than those that inhabit higher latitudes. Temperature is one of the factors that determines the growth, development, reproduction, and survival of plants. It is also important in physiological processes (Hardiansyah and Noorhidayati 2020).

Mangrove species in Madura coastal areas

Three species of mangroves, namely *Rhizophora stylosa* (Figure 5), *S. alba* (Figure 4), and *Avicennia marina* (Figure 6), were found in the present study area. The *R. stylosa* a type of mangrove that impressively inhabits both muddy and sandy substrates (Giesen et al. 2007), showcases its adaptability. According to Kint (1934), *R. stylosa* and *S. alba* mangroves usually live on sandy and rocky beaches in Indonesia. The *R. stylosa* mangroves have a fruit length of 20-30 cm, but sometimes it can be more than 54 cm (Giesen et al. 2007). The *S. alba* tends to inhabit sandy substrates. The characteristics for identification of *S. alba* are breath roots, open white, an average tree height is 15 m, unique round-shaped fruits, and oblong or round leaf shapes forming love. The *A. marina* mangrove species is a mangrove that is more often found on muddy substrates and has a high tolerance in saline conditions (Noor et al. 1999). The *A. marina* possesses a type of breathing root known as a pneumatophore. This root exhibits a pencil or cone-shaped morphology, protrudes above the substrate, and is characterized by numerous air-filled gaps that allow gas exchange. It is typically brown and reaches an average height of approximately 30 cm, with a diameter of about 1 cm (Tumangger and Fitriani 2019).

Taddan, Sampang District

This station has muddy characteristics because it is directly facing the beach. At station one, namely in the Taddan Village, Sampang District, three species were found, namely *S. alba* and *A. marina,* which consisted of trees and poles, also *R. stylosa* only at pole level. The mangroves found have a DBH ranging from 3.18 to 52.23 cm. The *S. alba* dominated 9 of 10 plots. The *R. stylosa*, at this station, there are only 35 individual poles. The number of *S. alba* at station one was 66 trees and 1 pole. In this site, *S. alba* is found at the pole level in limited abundance due to frequent displacement and transport of mangrove seedlings by tides. This phenomenon can be attributed to *S. alba* being the outermost species in this area, directly exposed to the sea. The *A. marina* species was found with 10 trees and 6 poles.

The *S. alba* likes waterlogged and muddy coastal areas, which is the character of the Taddan Village mangrove area. The mangrove type *A. marina* is a mangrove that has tolerance for high salinity of seawater because the higher the salinity, the faster the stimulation of growth *of A. marina* seeds, and vice versa if the salinity value is low; it will have an impact on plant growth and development (Cheng et al. 2020). In addition, *A. marina* mangroves also have good tolerance to metal content in the soil (Sholiqin et al. 2021). The *A. marina* mangrove can tolerate salt content in seawater; therefore, *A. marina* can be used as a phytoremediation agent, but based on Sholiqin et al. (2021) reports, it should not be used because it is only temporary and is considered ineffective. The *A. marina* mangrove has roots that are almost the same as the *S. alba* type, namely respiratory roots that come out of the soil surface (Pan et al. 2022).

Branta Tinggi, Pamekasan District

A sandy substrate characterizes this station; the species found in the 10 plots are all *R. stylosa* mangrove species, which consist of trees and poles with DBH ranging from 3.18 to 11.15 cm. The number of individuals at this station is 226 trees and 233 poles, and all are *R. stylosa* mangrove species. At the research location, the density of each individual is quite dense and they grow well in sandy areas. At the research location, 5 *R. stylosa* were taken, which were used to determine the type of mangrove being studied. The length of each Propagule is 35.2, 30.1, 29.8, 25.6, and 25.5 cm. The *R. stylosa* grows well in sandy areas and even in rocky areas. The stems of this type of mangrove can be used for charcoal production. The shape of this type of mangrove fruit is long and brown, and the flowers are yellowish white, usually consisting of 5-8 stems. The *R. stylosa* is a type of mangrove with a supporting root shape, like a brown chicken claw with more than two branches (Tumangger and Fitriani 2019). Mangrove plants that have roots usually live in sandy substrates or swamps; the sturdy roots of mangroves are useful for resisting waves and mud, protecting beaches from erosion and tidal waves (Tumangger and Fitriani 2019)

Tlanakan, Pamekasan District

This station has the characteristics of a sandy substrate and much plastic waste disposed of by the surrounding community. At this station, several dead mangrove plants were also found which were cut down by the community and which are characteristic of a beachside location. At the third station, mangrove species were identified, namely *R. stylosa, S. alba, and A. marina*, consisting of trees and poles with a DBH ranging from 3.50 to 25.48 cm. The most frequently encountered species was *R. stylosa,* with a presence of 146 at the tree level and 11 at the pole level. The second most common species was *A. marina,* recorded at 14 at the tree level and 1 at the pole level. The *S. alba* was exclusively found at the pole level, with a total of 11 poles. The *A. marina* in this station has a different character from other stations because the color of the leaves on the individuals found is greenish yellow. Generally, the *A. marina* leaves are green (Giesen et al. 2007). The difference in color on the leaves of *A. marina* at station 3 is caused by a lack of nutrition. According to Cheng et al. (2020), *A. marina* is a mangrove with a high tolerance to seawater salinity. However, this site may not be suitable for *A. marina,* resulting in nutritional deficiencies. According to Sholiqin et al. (2021), *A. marina* is more suited to living on sandy substrates; its flowers are yellow, and its fruit resembles nuts.

Song Osong, Sampang District

This station has characteristics of sandy and muddy substrates. The species types found were *R. stylosa, S. alba*, and *A. marina,* which consisted of trees and poles. The most dominant mangrove at this station is *R. stylosa,* totaling 145 trees and 21 poles; the muddy character of this station is suitable for *R. stylosa*. Other mangrove species were found at this location, namely *S. alba* by 9 and *A. marina* by 32, but the numbers were not as numerous as *R. stylosa*. This happens because the environmental character is not suitable for those three mangroves. The *S. alba* mangrove dominates the frontmost habitat zone or conservation zone between sea and land due to its ability to adapt to sandy and muddy environmental conditions (Haya et al. 2015). Not only does it dominate in the zone directly adjacent to the sea, but *S. alba* can also live in the middle zone. Just like *S. alba*, the habitat of *A. marina* is almost the same, dominating the muddy zone.

Species diversity of tree and pole-level mangroves

The species diversity index is used to measure the diversity of species in a vegetation community (Cavieres et al. 2014). The Shannon-Wiener Index (H') is used to analyze the species diversity index in this study. The mangrove diversity index value in this study refers to the categorization by Krebs (1989), where H'<1.5 indicates low diversity, 1.5≤H'≤3.5 indicates moderate diversity, and H'>3.5 for high diversity. According to Kim et al. (2017), the diversity index is strongly influenced by the number of individuals and species in an ecosystem. The higher the vegetation diversity index value, the more stable and mature the environmental conditions are (Jucker et al. 2014). The mangrove diversity index in this study is differentiated according to the identification of mangrove growth rates, divided into tree and pole species. Mangrove diversity index data at the tree and pole level at four research stations along the coast of Sampang and Pamekasan, Madura, are presented in Table 2.

The species diversity index is primarily influenced by species richness and evenness indices. According to Farista and Arben (2021), population unevenness and the dominance of certain species can result in a low diversity index value. An evenness index approaching 1 (J'=1) suggests that the number of individuals across different mangrove species is relatively uniform. In this research, the evenness values observed at all stations were significantly below 1, indicating an imbalance in individual numbers and the dominance of certain species within the community. At the tree level, the highest value was recorded at Taddan (0.27), followed by Tlanakan (0.23), Song Osong (0.21), and Branta Tinggi (0.05). At the pole level, the highest evenness values were found at Song Osong (0.48), followed by Taddan and Tlanakan (0.28), and the lowest value was Branta Tinggi (0.01). In Branta Tinggi, there is a very wide difference in the evenness index due to the presence of only one species, *R. stylosa*, despite the presence of a large number of species.

The species richness index revealed high species richness across the research stations. The highest richness index at the tree level was found at Branta Tinggi (95.58), followed by Tlanakan (71.68), Song Osong (65.70), and Taddan (39.34); at the pole level, the highest richness value was also observed at Branta Tinggi (98.00), followed by Taddan (24.03), Tlanakan (14.69), and Song Osong (13.61).

Table 2 shows the tree-level mangrove diversity index at all four study sites. The data presented in the table indicate the mangrove diversity index at the highest tree level in the study site, Song Osong, Tlanakan, Branta Tinggi, and Taddan, are 2.56, 2.32, 2.09, and 1.99, respectively. This value shows that the diversity of tree-level mangroves in the study site is grouped in the medium category. The tree-level mangrove that dominates the Taddan area is the *S. alba* species, with 66 individuals. Branta Tinggi is dominated by the mangrove species *R. stylosa,* with a total number of individuals of 226. Tlanakan is dominated by the mangrove species *R. stylosa* with 146 individuals. Song Osong's research site is also dominated by the mangrove species *R. stylosa*, with individuals 117. The table also provides the mangrove diversity index at the pole level for the four research locations. The highest values recorded were 2.19 in Song Osong, followed by 1.86 in both Tlanakan and Taddan and 1.85 in Branta Tinggi. These values suggest that the mangrove diversity within the study site is categorized as moderate.

Shannon-Wiener Diversity Index

The mangrove diversity index along the coasts of Sampang and Pamekasan District at both tree and pole levels is categorized as moderate, with values ranging from 1.99 to 2.56. The results fall within the range of H' values: $1.5 \leq H' \leq 3.5$ as a moderate level. This moderate diversity index suggests that the mangroves prefer a relatively stable ecosystem, benefiting from the existing vegetation in the area. The stability of these ecosystems, as evidenced by the moderate diversity index, is a testament to the resilience of mangrove forests. Consequently, this stability enhances the ecosystem's capacity to support further vegetation (Hardiansyah and Noorhidayati 2020). The results align with those of Akhrianti and Gustomi (2021), who examined the coastal area of Pangkalpinang City, Bangka Belitung Island Province, where the mangrove diversity index was categorized as low to moderate. Their research identified substrates predominantly composed of mud, sandy mud, sand, rocks, and coral fragments, indicating that the stability of mangrove vegetation communities in coastal areas is dependent on environmental parameters and substrate composition that facilitate mangrove growth.

Table 2. Tree and pole mangrove Shannon's Diversity Index, Margalef's Species Richness, and Pielou's Evenness Index

Species name	Amount	H'	Categories	D_{mg}	Categories	J'	Categories
Tree level mangrove							
Taddan Village							
Sonneratia alba J.E. Smith	66	1.99	Moderate	39.34	High	0.27	Low
Avicennia marina (Forsk.) Vierh.	10						
Branta Tinggi Village							
Rhizophora stylosa Griff.	226	2.09	Moderate	95.58	High	0.05	Low
Tlanakan Village							
Rhizophora stylosa Griff.	146	2.32	Moderate	71.68	High	0.23	Low
Avicennia marina (Forsk.) Vierh.	14						
Song Osong Beach							
Sonneratia alba J.E. Smith	25	2.56	Moderate	65.70	High	0.21	Low
Rhizophora stylosa Griff.	117						
Avicennia marina (Forsk.) Vierh.	3						
Pole level mangrove							
Taddan Village							
Rhizophora stylosa Griff.	35	1.86	Moderate	24.03	High	0.28	Low
Avicennia marina (Forsk.) Vierh.	6						
Sonneratia alba J.E. Smith	1						
Branta Tinggi Village							
Rhizophora stylosa Griff.	233	1.85	Moderate	98.00	High	0.01	Low
Tlanakan Village							
Rhizophora stylosa Griff.	11	1.86	Moderate	14.69	High	0.28	Low
Sonneratia alba J.E. Smith	11						
Avicennia marina (Forsk.) Vierh.	1						
Song Osong Beach							
Rhizophora stylosa Griff.	8	2.19	Moderate	13.61	High	0.48	Low
Sonneratia alba J.E. Smith	7						
Avicennia marina (Forsk.) Vierh.	6						

Note: H': Shanon's Diversity Index, D_{mg}: Margalef's Species Richness, J': Pielou's Evenness Index

Figure 4. Flowers and fruit of *Sinneratia alba* trees at Station 1 (Taddan Village) of Madura Coastal Beach, East Java, Indonesia

Figure 5. Flowers and fruit of *Rhizophora stylosa* trees at Stations 2, 3, and 4 (Branta Tinggi Village, Tlanakan Village, Song Osong Beach) on the Madura Coast, East Java, Indonesia

Figure 6. Flowers and fruit of *Avicennia marina* trees at Stations 1, 3, and 4 (Taddan Village, Tlanakan Village, Song Osong Beach) on Madura Coastal Beach, East Java, Indonesia

In this study, the substrate type identified at the research stations was predominantly muddy, with two stations exhibiting variations of sandy substrate. According to Salmo et al. (2013), the formation of mangrove stands is significantly influenced by soil characteristics. Research on the mangrove diversity index at the tree and pole level was also conducted by Akhmadi (2023) along the coast of Sampit Bay, Eas Kotawaringin. His study reported diversity index values of 0.64 for trees and 0.57 for poles, categorizing these indices as low. Akhmadi (2023) attributed the low species diversity index at both growth stages to the environmental conditions of the mangrove forest at the research site, which is characterized by a thick mud substrate that is frequently inundated and experiences low light intensity due to the dense canopy of mangrove trees.

Mangrove species threat

Based on the results obtained from the four stations, the diversity of tree and pole-level mangroves showed moderate diversity. According to Asadi et al. (2018), mangrove species with a moderate level of diversity are vulnerable to genetic differences and reduced genetic diversity, so they can affect the ability of mangroves to adapt to stressful conditions. Mangrove diversity is crucial in maintaining ecological balance and mangrove ecosystem services. However, mangrove diversity can face several threats, such as illegal logging and conversion of forest land to aquaculture areas. Mangrove trees cut down can directly cause changes in plant makeup and no longer function as a feeding ground and nursery ground suitable for various fish and shrimp of the economically important (Hidayah and Suharyo 2018). Threats caused by humans' excessive use of mangroves, mangrove habitat conversion, fisheries cultivation, and heavy metal pollution cause significant effects on mangrove ecosystems (Ashton 2022). According to Mughofar et al. (2018), mangrove forest vegetation in most areas has decreased in quality and quantity if it cannot be controlled, and the mangrove forests in the area will be damaged. According to Xie et al. (2020), the impacts of climate change, such as global warming, rising sea levels, and extreme weather patterns, are predicted to threaten mangrove ecosystems in the future. Climate change and sea level rise are also threats to mangrove species. Mangrove forests are vulnerable to changes in temperature, rainfall, salinity, and sea level. Climate change can affect the distribution, growth, and reproduction of mangrove flora and fauna and increase the effects of diseases, pests, and invasive species. Rising sea levels will slowly eliminate mangrove forest habitats, reducing the space used for mangrove forest expansion (Akram et al. 2023).

Efforts to protect mangrove forests

Mangrove forests play a crucial role in ecosystems, and their preservation should be ensured through various efforts, including conservation, restoration, and rehabilitation. According to Kiolol (2017), sustainable management can be achieved through two conceptual frameworks: strategic management and implementation, specifically focusing on the protection and rehabilitation of mangrove forests. These efforts should involve the indigenous community to ensure effective implementation (Sugiyanti and Hotimah 2020). The first aspect is protection, which can be implemented by establishing nursery centers, preservation of flora and fauna biodiversity along with their ecosystems, and promoting sustainable utilization practices. Protection efforts can be reinforced through the establishment of regulatory frameworks for designated areas. Rehabilitation initiatives can be implemented in collaboration with local government to enhance community knowledge of mangrove forest management. Active community involvement is essential to ensure that ecosystem maintenance is conducted routinely and sustainably (Dewi et al. 2023).

The conclusion that can be drawn from this study indicates that the mangrove diversity index along the coast of Sampang and Pamekasan District, at both tree and pole levels, falls within the medium category. The *R. stylosa, S. alba,* and *A. marina* were found in the study site. Specifically, the mangrove diversity index was highest at the research of Song Osong Beach (2.56), followed by Tlanakan (2.32), Branta Tinggi (2.09), and Taddan (1.99) at the tree level. For the pole-level mangrove diversity index, the highest values were recorded at Song Osong (2.19), Tlanakan and Taddan (1.86), and Branta Tinggi (1.85). The implementation of mangrove maintenance efforts can be achieved through protection and rehabilitation initiatives that collaborate with local governments and engage indigenous communities.

ACKNOWLEDGEMENTS

The researcher expressed his gratitude to the mangrove manager in Taddan Village, Tlanakan Village, Branta Tinggi Village, and Song Osong Beach and residents around the research area in Madura Island, Indonesia, who have given permission and the opportunity to conduct research in the mangrove area and thank all parties who participated both in the research and in the preparation of this article.

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INDO PAC J OCEAN LIFE
Volume 8, Number 2, December 2024
Pages: 94-100

P-ISSN: 2775-1961
E-ISSN: 2775-1953
DOI: 10.13057/oceanlife/o080204

Water resource sustainability in the coastal-karst area of Paranggupito Sub-district, Wonogiri, Indonesia

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Manuscript received: 28 October 2024. Revision accepted: 30 November 2024.

Abstract. *Aryanto AEP, Herbowo ACF, Aftsari AI, Maharani MP, Worokinkkin SPDA, Setyawan AD. 2024. Water resource sustainability in the coastal-karst area of Paranggupito Sub-district, Wonogiri, Indonesia. Indi Pac j Ocean Life 8: 94-100.* The karst region, with its unique geological landscape characterized by barren limestone hills, presents a significant challenge for the local population in processing clean water. Therefore, sustainable water source management is of utmost importance. This study aims to examine the community's perception of water sources, the communal management of water sources, water source management regulations, and the sustainability of water sources in three coastal-karst villages of Paranggupito Sub-district, Wonogiri District, Central Java, Indonesia, namely Gunturharjo, Gudangharjo, and Paranggupito. The method used in this research is a descriptive-qualitative approach. Primary data were obtained from interviews, questionnaire, and surveys conducted in the three coastal karst villages. While, secondary data on regulations on water source management were obtained from the Indonesian Law 17 of 2019 on Water Resources. This study shows that in the three coastal-karst villages most water sources are heavily influenced by the seasons. Based on interviews, 46% of the community obtains water for daily needs from communally managed water sources, while the remaining 54% manage their water or rely on privately owned dug wells. Otherwise, the regulations or applicable rules have not yet been implemented, so the management and sustainability of water resources are at risk. In terms of sustainability, the management of water resources can meet daily water needs for the next few years. Still, it does not guarantee the sustainability and quality of water, especially for drinking purposes.

Keywords: Coastal, karst, Paranggupito, springs, sustainability, water management

INTRODUCTION

Water is a vital resource for human life. According to Sulistyorini et al. (2016), water has many benefits, including being used by microorganisms for chemical reactions in the metabolic process and as a medium for transporting nutrients or metabolic waste. For humans, water is essential to meet biological needs, particularly for survival. Additionally, water is used for cooking, washing, irrigation, and even in industrial sectors. Thus, humans and other living beings cannot survive without water.

One concern regarding water resources is water security, which has emerged as a significant area of international academic interest (Jiang 2015). Water security is maintaining water-related hazards within reasonable bounds for human, environmental, and economic needs while providing an adequate amount and quality of water for human health, survival, and economic activity (Liu 2021). It is the fundamental component of the global objective of water and the key idea of sustainable development goals. All living creatures must carry out water management as an essential effort for survival (Yustikasari and Lulofs 2022). Periodic water management aims to prevent contamination of water sources.

An important area of concern in water resources management is the karst and coastal area. Karst is characterized by carbonate rock formations such as limestone, which change due to urban development. The fragile karst geological environment and rapid urbanization threaten the karst ecosystem, especially in areas close to urban centers (Tang et al. 2024). The karst region is hydrologically very complex (Pulido-Bosch 2021). Karst cavities formed by dissolution processes allow contaminants to seep directly into the groundwater system (Buckerfield et al. 2020). Karst aquifers have significant potential as a source of drinking water due to the substantial storage capacity they acquire with the breakdown of carbonate. The complex behavior of these aquifers concerning surface and subsurface flow is also caused by the breakdown of carbonate and the ensuing formation of preferential pathways (Cardoso de Salis et al. 2019). The thin soil in karst regions limits the natural filtering of contaminants from the surface to subsurface levels. Microorganisms are common contaminants in karst areas (Kaiser et al. 2023). Contamination can occur due to runoff from agriculture and livestock, and industrial activities may cause leaks from water pipes, septic systems, wastewater, stormwater runoff, and others. The formation of karst landforms, the scarcity of water resources, and their challenging use are the primary causes of the shortage of water resources in karst locations (Peng et al. 2021). Besides, coastal areas face many freshwater issues, including limited access, saltwater intrusion, and climate change. Climate change causes irregular rainfall or long dry seasons and increases the frequency of floods and droughts, which can worsen water pollution. These problems can have significant environmental and socio-economic consequences (Mukarram et al. 2023).

Water is the essential source of life for all living beings, including animals, humans, and plants. Water has many benefits, such as being a solvent, facilitating chemical reactions in metabolic processes, and serving as a medium for transporting nutrients and metabolic waste. For humans, water fulfills biological needs and is used for various purposes, such as cooking, drinking, washing, irrigation, and other necessities. Although water covers 70% of the earth's surface, the usable water supply is limited. It is not only the quantity that matters but also the quality of water, which must meet certain standards for specific uses. As population growth increases, so does the water demand, which impacts environmental quality.

Environmental degradation occurs when people pay little attention to environmental aspects, such as converting forest areas, which can cause erosion and sedimentation, thus directly or indirectly affecting water sources. According to Indonesian Law No. 17 of 2019, water resources include water, water sources, and energy. A water source is a natural or artificial reservoir found on, above, or below the ground surface. A spring is a groundwater that naturally emerges to the surface and can be influenced by seasonal changes, with quality similar to deep groundwater. Water emerges from the ground in a spring, typically in mountainous or highland areas. The formation of springs usually involves rainwater seeping into the ground and then emerging at the surface through cracks or fissures in the rock.

Geological and hydrological conditions influence the formation of springs in karst regions. Karst aquifers are considered extremely difficult to understand due to their unique features, like lines and flowing channels. Nonetheless, this aquifer system is highly diverse and dynamic, making it a valuable water conduit globally (Hillebrand et al. 2014). The dissolution process causes surface water to penetrate underground through cracks of various sizes quickly. From a chemical perspective, hard soil can neutralize acidity due to its alkaline nature. However, regarding its characteristics, water that enters the ground in karst areas cannot be retained because of the specific nature and gradation of karst soil.

Paranggupito is a sub-district in Wonogiri District, Central Java Province, Indonesia about 55 km from the capital city of Wonogiri District. The southern part of Wonogiri is a karst hilly region of the Gunung Sewu karst hills. This area spans three provinces, from Gunung Kidul in the Special Region of Yogyakarta to Wonogiri in Central Java and Pacitan in East Java. The karst region is a unique geological landscape characterized by barren limestone hills (Aprilia et al. 2021). Consequently, this morphology is considered to cause difficulties for the local population in accessing freshwater. The scarcity of freshwater arises due to the formation process and the dissolution pattern of limestone, which results in dry karst surfaces. According to Sudarmadji et al. (2014), more than 60% of Wonogiri District is prone to drought, indicating a clean freshwater crisis during the dry season, affecting the Paranggupito Sub-district. Three villages in this sub-district face the ocean, adding to the difficulty of providing clean fresh water.

This research aims to determine the community's perception of water sources, the communal management of water sources, water source management regulations, and the sustainability of water sources in Paranggupito Sub-district, Central Java, Indonesia especially in coastal villages of Gunturharjo, Gudangharjo, and Paranggupito.

MATERIALS AND METHODS

Study area

This research was located in three coastal-karst villages of Gunturharjo, Gudangharjo, and Paranggupito in Paranggupito Sub-district, Wonogiri District, Central Java, Indonesia (Figure 1).

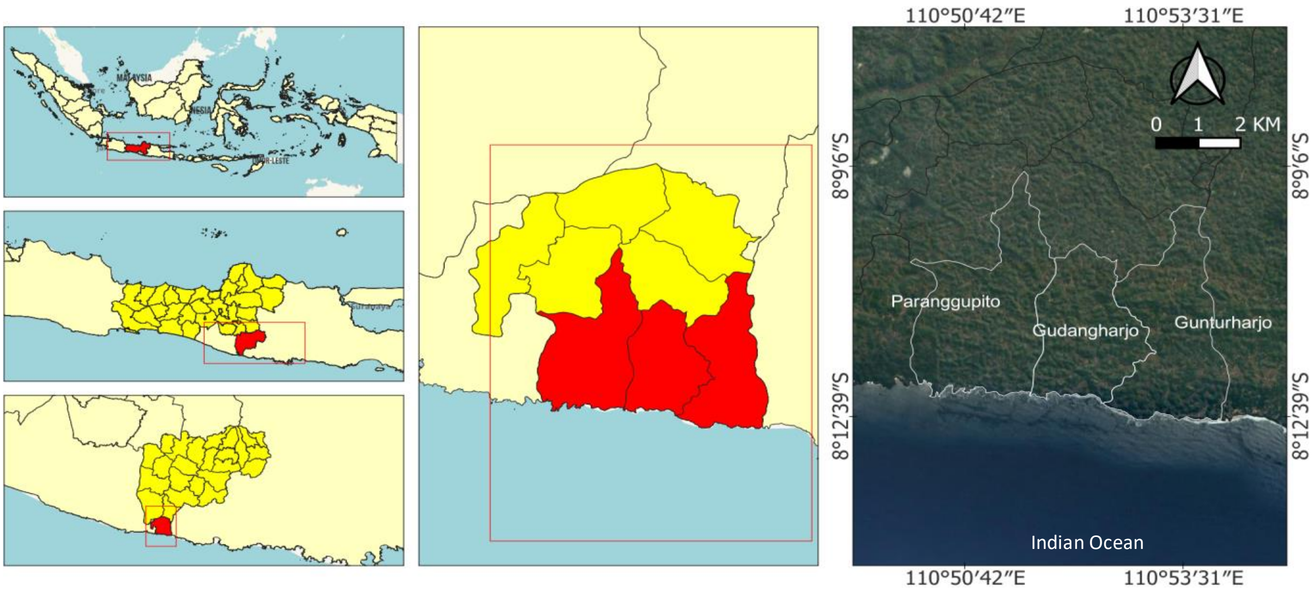

Figure 1. Location of coastal karst area of Paranggupito, Gudangharjo, and Gunturharjo Villages, Paranggupito Sub-district, Wonogiri District, Central Java, Indonesia

Most of the population in these areas works as farmers and livestock breeders, which makes water a critical "ingredient" for carrying out their work. This region is located in the hills where the land is a karst area, a distinct kind of landscape that develops on top of highly soluble materials like gypsum, marble, and limestone (Zerga 2024). This area also borders directly on the Indian Ocean. Water resource vulnerability is one of the main problems in this coastal karst area (Cahyadi et al. 2017).

Sampling/data collection and data analysis

The method used in this research is a qualitative descriptive study, which is a research method aimed at describing and understanding social phenomena related to water. This method is presented through a single case study analysis. The data sources for this research come from both primary and secondary data. The primary data were obtained through field surveys, interviews, and descriptive questionnaires in the three villages. Interviews were conducted with 100 respondents. Respondent characteristic data only includes age and residence, to ensure that respondents are adults and live in the research villages. Several assessment criteria were used to evaluate (i) the community's perception of water sources, (ii) the communal management of water sources, (iii) water source management regulations, and (iv) the sustainability of water sources. Secondary data were obtained from Indonesia Law Number 17 of 2019 on Water Resources. The primary data collected were then analyzed using a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis to assess water-related criteria in these three coastal-karst villages.

RESULTS AND DISCUSSION

The Community's perception and utilization of water sources

Based on the data obtained (Table 1), most (61%) of the population living in the study area still have water sources in the form of springs near their homes, but not all of it is used to meet daily needs. In terms of their origin, springs are groundwater that naturally emerges to the surface, with an output quality that is the same as deep groundwater. According to the interview, most of the spring quantity in the research area is highly influenced by seasonal changes (91%). Wells tend to dry up during the dry season and have water during the rainy season. Even so, the quality (96%) and quantity (100%) of the water are sufficient to meet their needs. However, the increasing population has led to a surge in water demand, necessitating the exploration of alternative water sources to meet domestic, agricultural, and commercial needs (Sulistyani and Irianto 2018).

Table 2 shows the utilization of the water supply system in the study area (Gunturharjo, Paranggupito, and Gudangharjo Villages, Wonogiri District). Residents close to springs, usually dig wells (36%) or draw the water using pipes provided by themselves (*Independent piping*) if the location is some distance from the house (10%). Besides that, people seek other alternatives for gaining access to water, such as purchasing water from trucks with tank systems, using drilled wells for very deepwater sources, and relying on *Sistem Penyediaan Air Minum* (SPAM) and *Perusahaan Daerah Air Minum* (PDAM). The local government manages PDAM, while private entities manage SPAM, which provides and distributes clean water to the community. Water is distributed through pipes connected from reservoirs and delivered to households. Based on Table 2, the majority of the community in the study area uses water sources from SPAM/PDAM (46%). Some residents who live near water springs prefer to use SPAM/PDAM because it is easier and more secure to operate than using dug wells or independent pipes.

The other alternative to access water sources is using Rain Water Harvesting (RWH), which is used in 2 households. It is a technique for collecting and storing rainwater for future use. RWH uses different methods, all of which demonstrate adaptability to local conditions. In Brazil, rainwater is collected in tanks that are partially buried in the ground to prevent contamination by other substances and to maintain water quality (WAW Foundation 2024). In Thailand, rainwater is stored in jars that can hold 100-3000 liters per jar, a system used in areas with a six-month dry season (CSE 2023). In Indonesia, RWH has been implemented in Gunung Kidul, using storage tanks made of cement/concrete, brick walls, or plastic drums, which can supply clean water to communities during the dry season (Pujiati et al. 2018).

Table 1. Community perception of water source management

Questions	Yes (%)	No (%)
Are there any springs around your residence?	61	39
Is the water source sufficient to meet your needs?	96	4
Is there a difference in water flow during dry season?	91	9
Is the water of good quality and suitable for use?	100	

Source: Primary Data, 2024

Table 2. The utilization of the water supply system

Question	Dug Well	Independent piping	Rainwater harvesting	Tank system	Drilled well	SPAM/PDAM
Community water source	36	10	2	6	1	46
Total			100			

Table 3. Perception of communal water source management in the study area

Questions	Yes (%)	No (%)
Are there any springs managed communally?	25	75
If the springs are managed communally, are you a consumer of that communal water management system?	100	0
Is the management system for the springs well-maintained?	95	5
Are there frequent issues in the management of communal water sources?	15	85
Are the managers responsible for addressing those issues?	100	0

The Communal management of water sources

Some members of the community in Paranggupito Sub-district use clean water managed communally. Table 3 shows that 25% of the springs in the study area were managed communally, while the remaining 75% were managed individually. Communal management involves providing water sources from PDAM or SPAM. According to interview results, the issues faced in the management of communal water sources include occasional interruptions in water flow.

Additionally, the community believes water from wells or groundwater is more precise and cleaner than water from PDAM/SPAM, which contains many calcium compounds. The water from SPAM/PDAM is clear, but some have a salt content that makes it similar to hard water. Water hardness refers to the levels of dissolved calcium and magnesium in the water. There are two types of water hardness, i.e.: temporary hardness and non-carbonate (permanent) hardness (Kiswanto 2022). This water cannot be consumed directly just by boiling; it also needs to be settled. Water with high hardness can cause various issues, such as gray staining on clothes and reduced water flow in distribution pipes (Sahabuddin 2015). This water quality is not ideal for daily consumption. Therefore, the community is encouraged to seek alternative solutions to address this issue, such as desalination or finding better freshwater sources (Wardana et al. 2024).

This aligns with research conducted by Serniati et al. (2021), which shows that some community members prefer using well water because SPAM water contains calcium compounds. Pump lines are connected using a piping system. Corrosion of pipes in drinking water distribution systems is of particular concern because of various problems related to the loss of pipe mass through oxidation to dissolve, which shortens the service life of pipes and increases maintenance costs. Another problem is that scale can accumulate in tubercles, reducing water capacity and thereby increasing pumping costs, which also impacts consumer health (Liang et al. 2014). However, communal water supply from PDAM/SPAM is also considered quite effective as it can serve as a backup during the dry season. Although there are still issues in managing communal water in Paranggupito Sub-district, the managers of communal water sources have been responsible for identifying and resolving these problems.

Water source management regulations

The regulation concerning water source management currently used in Indonesia is Law Number 17 of 2019 on Water Resources. According to this law, the regulation addresses the imbalance between the demand and availability of water, as the quality and quantity of water have declined over time. Furthermore, there is a need to manage water resources that consider social, environmental, and economic aspects to achieve integration in meeting the community's clean water needs. Water is a vital production branch and one of the keys to sustainable living, as the state controls it for the benefit and welfare of the people.

There are two patterns in formulating legislation related to government authority, i.e.: the broad autonomy pattern and the regional autonomy pattern (Wulandari and Ilyas 2019). The broad autonomy pattern gives authority to the central government, while the remainder is under the regional government's authority. In contrast, the limited autonomy pattern primarily grants authority to the regional government in a restrictive manner, with the remainder under the central government's authority. However, the established regulations have not reached remote areas that fundamentally need regulations to manage water sources. Based on interviews conducted in three villages in Paranggupito Sub-district, these villages have not implemented existing regulations. This urgent situation highlights the need for immediate action to ensure the management and sustainability of water resources in these remote areas.

The community in these villages relies solely on the nearest water sources and waits for rainfall to meet their clean water needs. The government has not introduced the residents of Paranggupito Sub-district to the regulations applicable to water resource management, and there is a lack of socialization regarding regulations and local wisdom that should be established for the protection of clean water. However, the implementation of local wisdom is the cultural knowledge possessed by a specific group of people, including cultural knowledge related to the sustainable management and utilization of natural resources, which holds great promise. It reflects the mindset of the community concerning the functions of the environment, nature's responses to human actions, and the relationship between humans and their environment. By promoting and implementing local wisdom, we can bring about a positive change in the water management situation in Paranggupito Sub-district.

The sustainability of water sources

The sustainability of water sources in Paranggupito Sub-district, Wonogiri District, is an issue that must be prioritized. This region often experiences water shortages during the dry season, a situation that significantly impacts the lives of the local communities. Water shortages hinder water use for agricultural needs, forcing landowners to delay planting and focus on soil preparation while waiting for the rainy season.

The availability of water resources in karst areas differs significantly from that in non-karst regions. Springs in karst areas exhibit uneven water distribution, which is a contributing factor to the water shortages experienced by communities in karst regions. The scarcity of water in karst areas is due to the formation of underground drainage systems, making the surface areas vulnerable to drought (Arida 2022).

The groundwater conditions in karst areas possess distinctive characteristics. These groundwater conditions depend on the dissolution processes occurring in the limestone of the area. Most of the soil patterns in karst regions consist of cracks or fissures in the rocks, leading to unpredictable water distribution. Generally, groundwater resources in karst areas consist of three types: springs, dug wells, and independent piping systems. Many residents utilize dug wells in this region because there are relatively abundant water resources beneath the ground. However, not all areas have springs or water reservoirs. Springs/water reservoirs are only found in Gunturharjo Village and parts of Gunturharjo. In addition to these three water sources, the community also has Rain Water Harvesting (RWH) systems. The RWH system is a structure around the house that serves as an alternative water storage facility. This RWH relies solely on rainwater, and the surrounding community mainly uses it for agricultural purposes.

Through interviews conducted with residents in the karst area, it was found that the water available for their daily needs is sufficient for several years ahead (Table 1). Still, it does not guarantee sustainability and adequate water quality, especially for drinking. This is also related to the lack of government regulations applied in this area. Regulations and the sustainability of water resources are interrelated and go hand in hand. If there are binding regulations governing water resource management, the sustainability of both water quality and quantity can be maintained and protected collectively.

Recommendations for water management

Water management recommendations for the karst area in Paranggupito Sub-district are determined based on a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis. Strengths and opportunities drive good water governance, while weaknesses and threats limit water management. The driving and limiting factors are categorized into internal factors (strengths, weaknesses) and external factors (opportunities, threats); strengths and opportunities can be leveraged to address weaknesses and threats (Rachid et al. 2021).

Based on the SWOT analysis results in Table 4, recommendations for water management in the coastal-karst area of Paranggupito Sub-district include collaboration between the community, government, and companies as CSR implementers. According to Bajec and Krajc (2023), water management through a participatory approach requires active community involvement in conserving water sources to achieve sustainable development and address water scarcity. The potential impact of these CSR programs is significant, offering hope for a future with improved water management. These programs can include outreach to improve human resource quality and community participation in planning and decision-making regarding water management (Caponera and Nanni 2019).

Table 4. Perception of communal water source management in Paranggupito Sub-district, Wonogiri District, Central Java, Indonesia

	Internal / External	Strengths (S)	Weakness (W)
		1. The water sources around the community settlements are available. 2. The groundwater quality is still considered clear and suitable for drinking water. 3. Most springs meet the domestic needs of the community. 4. Most water source locations are close to homes, with a radius of less than 10 meters.	1. Inadequate economic conditions occur in providing water source infrastructure. 2. Lack of supervision and strict regulations in water utilization. 3. Water discharge cannot meet the needs of agricultural systems. 4. Lack of knowledge and awareness about water resource management practices.
Opportunity (O)	1. The opportunity for CSR (Corporate Social Responsibility) was the programs for the provision of clean water resources.	1. Collaboration between the community, companies, and the government managed to implement clean water programs, such as constructing boreholes. 2. Utilize existing springs around community settlements to be managed communally with a more structured governance system.	1. Develop water sources through financing via CSR. 2. Implement applicable regulations and establish agreements/specific rules between managers and the community regarding the utilization of water sources. 3. Strengthen human resource capacity for water source management.
Threats (T)	1. Increased demand and need for water. 2. Climate change. 3. Decreased water availability occurs during the dry season.	1. Create a rainwater harvesting system (RWH) as a backup water source during the dry season. 2. Enhance the water conservation efforts to ensure that needs are met sustainably.	1. Enhance the roles and partnerships in providing clean water. 2. Encourage the research on clean water management in karst areas. 3. Apply the appropriate technology to address clean water limitations.

The government plays a role in implementing regulations that support integrated water management and programs related to providing clean water in Paranggupito Sub-district. The government also plays a crucial role in providing assistance, facilities, and appropriate technology to meet community water needs. According to Angelia and Hakiki (2021), companies or private partners are essential in providing financial assistance; through CSR programs, they can contribute to meeting clean water needs in Paranggupito Sub-district. Based on interviews, there are plans for a CSR program in Gudangharjo Village, but it has not yet been realized. Additionally, research on managing water sources in karst areas is needed. Most scientific applications related to water involve some form of monitoring, but participatory activities such as mapping, modeling, and local data collection are valuable data sources (Walker et al. 2021). Integrating local knowledge can be used for disaster risk reduction at the community scale (Hicks et al. 2019).

The springs in Paranggupito Sub-district meet community needs, but there are differences in discharge during the dry season. Efforts to address drought during the dry season include providing rainwater harvesting systems and planting crops adaptive to dry conditions (Wijayanti and Noviani 2020). A simple rainwater harvesting example involves collecting the rainwater into a well fed from the roof via gutters, then filtering it using containers filled with gravel or charcoal before it reaches the well or tank (Bajec and Krajc 2023). Water sources can be managed in karst areas by increasing vegetation density to extend the delay time for water and pollutants entering the soil layer (Riyanto et al. 2020). Karst ecosystems can naturally provide high-quality drinking water that can be utilized through springs such as wells. However, a good understanding of the characteristics of karst aquifers is crucial for efficiently protecting and sustainably utilizing water (Golob et al. 2019).

In conclusion, it was found that in the three coastal karst villages of Paranggupito Sub-district, Wonogiri District, the majority of water sources are significantly affected by the seasons. According to the interview results, 46% of the community manages water sources communally, while 54% are managed individually or through private wells. The water sourced from SPAM managed communally is clear; however, some have salinity levels similar to hard water. In this area, regulations or applicable rules have not yet been implemented. As a result, the management and sustainability of water resources are at risk. In terms of sustainability, the management of water resources can meet daily water needs for the next few years. Still, it does not guarantee the sustainability and quality of water, especially for drinking. However, there is hope in the form of the CSR program plans, which, if realized, could significantly improve the situation. Additionally, research on managing water sources in karst areas is needed.

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INDO PAC J OCEAN LIFE
Volume 8, Number 2, December 2024
Pages: 101-111

P-ISSN: 2775-1961
E-ISSN: 2775-1953
DOI: 10.13057/oceanlife/o080205

Mangrove dynamics on the Madura Island coast, Indonesia, analyzed through NDVI: Balancing degradation and restoration efforts

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Manuscript received: 25 November 2024. Revision accepted: 30 December 2024.

Abstract. *Ramadhani G, Wahyuningtyas J, Arifiandita DM, Ayuningtyas HR, Deristani A, Ulumuddin YI, Setyawan AD. 2024. Mangrove dynamics on the Madura Island coast, Indonesia, analyzed through NDVI: Balancing degradation and restoration efforts. Indo Pac J Ocean Life 8: 101-111.* Mangrove ecosystems are plant communities that thrive at the interface between land and sea, but they face significant threats, particularly from land conversion. The mangrove forests along the coast of Madura have experienced a decline in coverage due to such conversion. This study offers valuable insights into changes in mangrove areas and uses NDVI analysis to assess these changes from 2019 to 2024. The study focuses on monitoring mangrove forest distribution and changes in the Bangkalan, Sampang, Pamekasan, and Sumenep coastal areas. Primary data were obtained from Sentinel-2A - 2A satellite imagery of Madura. Data analysis used the Kappa Analysis method to validate mangrove density classification. Results showed an increase in mangrove coverage in Bangkalan between 2019 and 2024, with the moderately dense category rising from 348.9 to 355.3 hectares and the dense category increasing from 114.7 to 150.1 hectares. Similarly, in Pamekasan, the moderately dense classification grew from 305.4 to 409.3 hectares. However, overall, the reduction in mangrove forest area was more significant than the increase. The Kappa accuracy of 70% indicated moderate reliability, with data discrepancies in 14 out of 40 points. In Madura's mangrove forests, conservation efforts include education, conservation initiatives, and community empowerment through sustainable environmental communication strategies.

Keywords: Density, health, kappa coefficient, mangrove, NDVI

INTRODUCTION

Mangrove ecosystems are plant communities that thrive between sea and land, are influenced by tidal movements, and are commonly found in shallow bays, estuaries, and deltas (Rizqi et al. 2023). Their adaptive root systems protect coastlines from erosion and tsunamis (Shiau et al. 2020). However, mangroves are threatened by human activities, including urbanization and industrial expansion (Hidayah et al. 2015). As the country with the most extensive mangrove coverage, Indonesia must prioritize sustainable management and conservation of these essential ecosystems (Sidik et al. 2018).

According to data from the Geospatial Information Agency (GIS), Indonesia's mangrove forests covered 3.36 million hectares in 2017 (Rahadian et al. 2019). In Madura, mangroves extend over 12,115.8 hectares, distributed across several areas: Bangkalan (1,508.1 hectares, 10%), Sampang (915.3 hectares, 6.1%), Pamekasan (599.3 hectares, 4%), and Sumenep, including its islands (12,095.4 hectares, 80%) (Muhsoni et al. 2019). The protection of mangrove forests involves monitoring through remote sensing and GIS technologies, which utilize satellite imagery for accurate mapping (Giri et al. 2021). Due to their location between land and sea, mangroves exhibit unique spectral characteristics that necessitate specific transformations of vegetation indices for effective detection (Kawamuna et al. 2017).

In 2017, Indonesia's mangrove forests covered 3.36 million hectares (Rahadian et al. 2019), with Madura accounting for 12,115.8 hectares: Bangkalan (10%), Sampang (6.1%), Pamekasan (4%), and Sumenep (80%) (Muhsoni et al. 2019). Mangrove protection can be improved using remote sensing and GIS, which leverage satellite imagery for precise mapping (Giri et al. 2021). Due to their transitional location between land and sea, mangroves require specific spectral transformations, often using vegetation index techniques, for accurate detection (Kawamuna et al. 2017).

Mangrove ecosystems are evaluated based on species diversity, density, canopy cover, and biomass (Schaduw et al. 2019). In Indonesia, over 70% of mangroves are damaged due to human activities. Madura's mangroves span 15,118.2 hectares, with 8,794.1 hectares in good condition and 6,324.1 hectares degraded (Hidayah et al. 2024). Logging, land conversion, and waste disposal have significantly reduced mangrove coverage and health, especially along Madura's coast (Hidayah 2015; Rosyid et al. 2021).

Satellite imagery allows for the analysis of mangrove ecosystems using vegetation indices such as NDVI, which is known for its accuracy and correlation with vegetation density (Razali et al. 2019). The Mangrove Health Index (MHI) evaluates ecosystem health based on parameters like stem diameter, canopy cover, and density using field data or satellite imagery (Hidayah et al. 2023). Research by Nurdiansyah et al. (2021) demonstrates a strong correlation between these parameters and vegetation indices, which can be derived from satellite image analysis. MHI values can be predicted using several vegetation indices, including NBR (Normalized Burn Ratio), GCI (Green Chlorophyll Index), SIPI (Structure Insensitive Pigment Index), and ARVI (Atmospherically Resistant Vegetation Index).

Mangrove density has a close relationship with the dynamics of mangrove area change from 2019 to 2024 on the south coast of Madura. Increases in mangrove density often reflect successful natural regeneration or successful rehabilitation programs, such as mangrove planting in previously degraded areas. Conversely, a decrease in mangrove area can occur due to the pressure of human activities, such as land conversion to salt ponds, as well as the impacts of coastal abrasion and climate change. The aims NDVI analysis shows that changes in mangrove area in the period 2019-2024 with increasing pressure on mangrove land on the south coast of Madura, sustainable management efforts are needed to maintain a balance between optimal mangrove density and the sustainability of its area to support the coastal ecosystem as a whole.

MATERIALS AND METHODS

Study area

This study monitors the distribution and changes in mangrove forest coverage along the coast of Madura Island, specifically focusing on mangrove dynamics from Bangkalan to Sumenep (Figure 1). Located near the equator, Madura Island is one of the driest regions in Indonesia, characterized by high temperatures and low humidity levels (Wasonowati et al. 2019). Temperatures along the Madura coast range from 23 to 31°C year-round; humidity in the coastal areas varies between 42 and 92%, depending on rainfall and other factors. The average annual rainfall on Madura Island ranges from 1,328 to 1,571 mm, with December typically experiencing the highest rainfall, averaging up to 275 mm (Agustin and Syah 2020).

Factors influencing the weather on the coast of Madura Island include flat topography, monsoon wind speed and direction, mangrove conditions, sea surface temperatures, human activities, and other atmospheric and oceanographic factors. Each mangrove species has varying tolerance to salinity. For example, *Avicennia* spp. can tolerate salinity levels up to 85 ppm, while *Bruguiera gymnorhiza* thrives in areas with salinity levels between 10 and 37 ppm (Natarajan et al. 2021). Most mangrove plants achieve their highest leaf production rates at temperatures between 26 and 28°C and pH levels of 8 to 9 (Martínez-Díaz and Reef 2023).

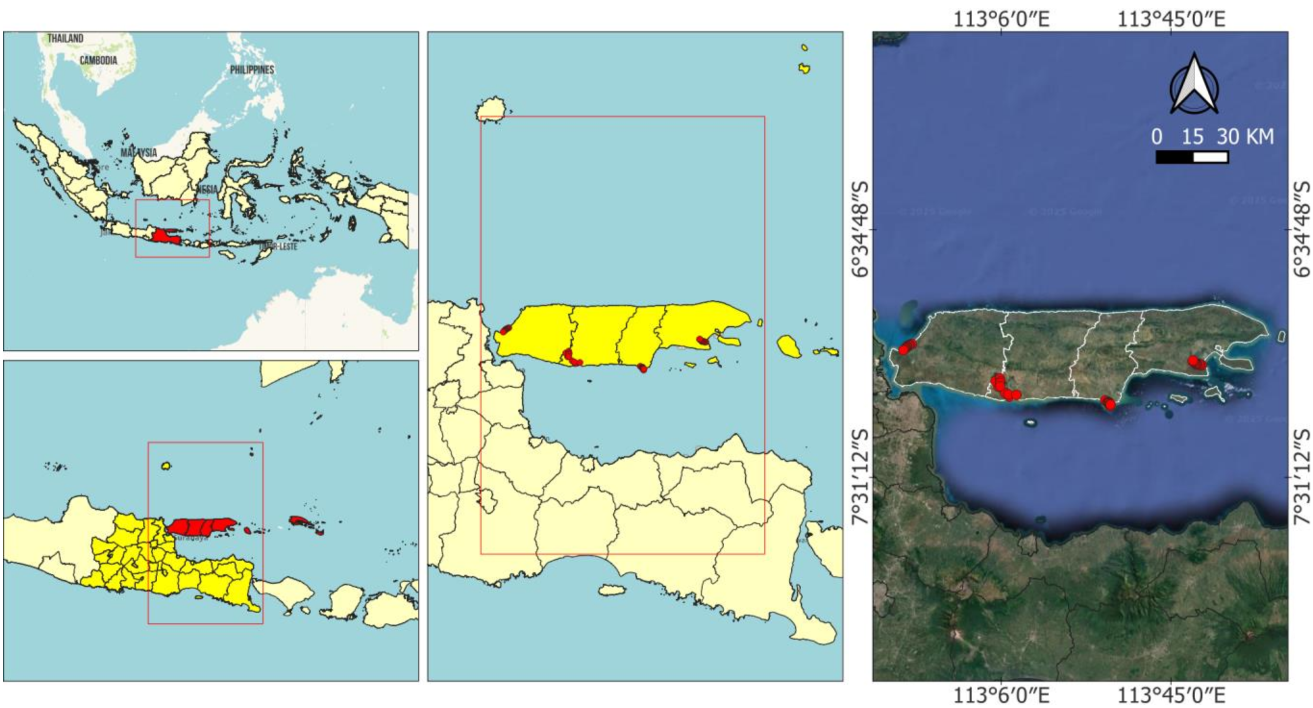

Figure 1. The study Area on the coast of Madura Island, East Java Province, Indonesia, includes 4 districts, i.e.: Bangkalan, Sampang, Pamekasan, and Sumenep

The study area for mangrove forest coverage on the coast of Madura Island (Figure 1) includes Bangkalan District (112°40'06"-113°08'04" E and 6°51'39"-7°11'39" S), Sampang District (113°08'-113°39' E and 6°05'-7°13' S), Pamekasan District (113°19'-113°58' E and 6°51'-7°31' S), and Sumenep District (113º32'-116º16' E and 4º55'-7º24' S). The coast of Madura Island experiences stronger abrasion and accretion currents compared to the northern coast, with higher levels of human activity. In 2023, Madura Island had a population of approximately 4.1 million people, with 905,151 residents in Bangkalan District and 1,042,276 in Sumenep District (BPS East Java Province 2023). Land use on Madura includes settlements, rice fields, farms, dry land, salt ponds, and mangrove forests (Hidayah and Suharyo 2018). The mangrove species commonly found in the area include Avicenniaceae, *Rhizophora*, *Avicennia marina*, *Bruguiera gymnorhiza*, *Acanthus ilicifolius*, and others (Rosadi et al. 2018).

Procedures

Types and sources of data

The primary data used in this study are Sentinel-2A imagery, selected for analyzing mangrove density along the coast of Madura Island in 2019 and 2024. Sentinel-2A imagery was obtained from the USGS Earth Explorer data portal. Sentinel-2 imagery is commonly used for monitoring spatial dynamics, especially in mangrove areas (Wang et al. 2018). Secondary data include administrative maps of Madura Island, QuickBird maps (Google Earth), and relevant literature reviews. The administrative maps were obtained from the Geospatial Information Agency (Badan Informasi Geospasial, BIG) of Indonesia

Processing method

The processing method involved transforming Sentinel-2A imagery of the Madura coastline using band combinations to create vegetation indices. The index used in this study is the NDVI (Normalized Difference Vegetation Index). The principle of NDVI is to measure the level of greenness intensity using the following formula (Naharudin 2021):

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$$

Where:
NIR: Near Infrared (Band 8)
Red: Red Band (Band 4)

Near Infrared (Band 8) and Red Band (Band 4) are bands sensitive to the chlorophyll content in plant leaves, which serves as an indicator of vegetation distribution (Zhen et al. 2021). The formula can indicate NDVI values for the target area. According to Hanif (2015), NDVI values range between -1.0 and 1.0. Based on vegetation density, NDVI values are classified into four categories: water/cloud, non-vegetation, sparse, moderately dense, and dense (Table 1). This research utilizes ArcGIS 10.8 software to generate NDVI maps through spatial analysis.

Table 1. NDVI value classification

Vegetation density classification	NDVI Value
Cloud and water	-2 - 0
Non vegetation	0 - 0.2
Low dense	0.2 - 0.4
Moderate	0.4 - 0.6
Dense	0.6 - 0.8

Source: Hardianto et al. 2021

Validation

For validation, random sample points were generated on the mangrove area map along the coastline of Madura Island. A total of 40 sample points were selected: 10 along the Sumenep coast, 10 along the Bangkalan coast, 10 along the Pamekasan coast, and 10 along the Sampang coast. These points were selected based on the presence of mangroves, ease of access to data, and the inclusion of all four regencies on Madura Island to ensure comprehensive coverage. The classification results for each point were then compared with NDVI values using QuickBird map imagery from Google Earth. Validation was performed visually by interpreting the predetermined sample points with QuickBird imagery on Google Earth.

Data analysis

Kappa analysis was performed to validate the classification of mangrove density by comparing the classification results from processed image data with field observation data using a confusion matrix (Sari et al. 2022). The confusion matrix (Table 2) serves as a tool to measure data accuracy through simple cross-tabulation. This process involves assessing the agreement between image-processed data and field observation data, providing a basis for evaluating data accuracy. The matrix includes mangrove density classes derived from image classification in its rows and density classes based on field observations in its columns, with the matrix contents representing the number of objects.

The more objects that match the classes in the rows and columns, the higher the accuracy of the mangrove health classification results (Mappiasse et al. 2022). The accuracy of the image classification results is calculated using the overall accuracy, producer's accuracy, and user's accuracy (Vu et al. 2022). The overall accuracy shows the percentage of correctly classified findings based on the observation data with the following formula:

$$overall\ accurancy: \frac{XKK}{N} \times 100\%$$

Where:
XKK: number of observation points that match
N : total number of observation points

Table 2. Matrix of classification density results agreement with field observations

Mangrove density analysis	Field observation data						Producer's accuracy
	Cloud and water	Non vegetation	Low dense	Moderate	Dense	Total	
Cloud and water	XAA	XAB	XAC	XAD	XAE	∑EC	XAA/∑AC x 100%
Non vegetation	XBA	XBB	XBC	XBD	XBE	∑BC	XBB/∑BC x 100%
Low dense	XCA	XCB	XCC	XCD	XCE	∑CC	XCC/∑CC x 100%
Moderate	XDA	XDB	XDC	XDD	XDE	∑DC	XDD/∑DC x 100%
Dense	XEA	XEB	XEC	XED	XEE	∑EC	XEE/∑EC x 100%
Total	∑AR	∑BR	∑CR	∑DR	∑ER	N	
Producer's accuracy	XAA/∑AR x 100%	XBB/∑BRx 100%	XCC/∑CRx 100%	XDD/∑DRx 100%	XEE/∑ERx 100%	XKK	

Note: ☐: Suitable, ☐: Unsuitable; Source: Abimanyu et al. (2019)

It is known that the total number of sample points obtained is 40, which are randomly distributed, with each district having 10 sample points. These points were selected to obtain the overall accuracy, with the aim of measuring the user's accuracy and the producer's accuracy. The mangrove density classification results can be accepted if the overall classification result reaches >85% (Wicaksono and Wicaksono 2018).

RESULTS AND DISCUSSION

Results

The coastal area of Madura, vulnerable to exploitation, faces increasing pressure from the economic needs of local communities dependent on land use for salt production and aquaculture. The mangrove forest area along the Madura Strait Coast in Sumenep, Pamekasan, Sampang, Bangkalan, Gresik, Surabaya, Sidoharjo, Mojokerto, Pasuruan, Probolinggo, Situbondo, until Bondowoso has decreased by 111.82 hectares (Hidayat and Suharyo 2018). As a result, mangrove coverage shrinks, disrupting its ecological functions and increasing the risk of environmental disasters such as abrasion and seawater intrusion. The decline in NDVI values of mangroves in this region not only impacts the local environment but also undermines the resilience of coastal ecosystems on a regional scale.

The NDVI map of the Bangkalan Coast, derived from Sentinel-2A imagery, is shown in Figure 2. The map highlights areas with high mangrove density along the western coast and a small section on the southeastern side. Different colors represent varying NDVI values. The density of other vegetation types, including shrubs, yard plants, and rice fields, can also be observed in the area. In 2019, the western coast of Bangkalan exhibited dense mangroves, with NDVI values ranging from 0.3 to 0.8, indicating a healthy mangrove population. Mangrove density refers to the concentration of mangrove trees along Madura's coastal areas. Madura's mangroves cover approximately 15,118 hectares across four main districts: Bangkalan, Sampang, Pamekasan, and Sumenep. Mangrove density is measured using satellite imagery methods, such as Landsat 8, which analyzes the Normalized Difference Vegetation Index (NDVI). This data is then compared with field observations to assess the condition and distribution of mangroves. A slight protrusion in the middle of the Bangkalan Coast, observed in both 2019 and 2024, suggests low mangrove density. This is likely due to the presence of built-up areas.

The distribution of mangroves was very dense along the Sampang coast and rivers in 2019 but decreased to dense mangroves in 2024 (Figure 3). This decline may be attributed to anthropogenic activities that have impacted mangrove density in the Sampang Coast area. The dominant density classes in the Sampang coastal region are very low and low density. Very dense mangrove was found along the coastal river channels of Sampang. Compared to the regencies of Bangkalan, Sumenep, and Pamekasan, Sampang experienced a reduction of 210.08 hectares in mangrove forest area (Hidayat and Suharyo 2018).

In 2019, very dense mangroves were identified along the Pamekasan coast, but by 2024, their density had decreased to a dense classification (Figure 4). This change may be caused by anthropogenic activities that could affect mangrove density in the Pamekasan Coast area. Looking at the dominant density classes in the Pamekasan area, there are three density classes: very dense, dense, and moderate. Very dense vegetation was identified along the Pamekasan coast.

In 2019, very dense mangroves were identified in the central area of Sumenep, but by 2024, their density had decreased to a dense classification (Figure 5). This change may be caused by anthropogenic activities that could affect mangrove density in the Sumenep area. The dominant density classes in the Sumenep area are moderate and low density. Very dense mangrove was identified only in the central part of the Sumenep area. Built-up land in Sumenep has increased, particularly in productive agricultural areas (Saputra et al. 2022).

Based on Table 3, the overall Kappa accuracy test for 40 observation points resulted in a value of 70%, indicating poor performance. The data matching the classification results and field observations included 21 points classified as very dense and 5 points as dense. The remaining 14 points showed discrepancies. One factor contributing to the differences between field observations and the NDVI mangrove density analysis results is the time discrepancy between image acquisition and field observations. High-resolution images do not necessarily ensure easier interpretation, as errors can still occur, such as differences in the timing of image acquisition and the presence of similar natural features (Naufal et al. 2022).

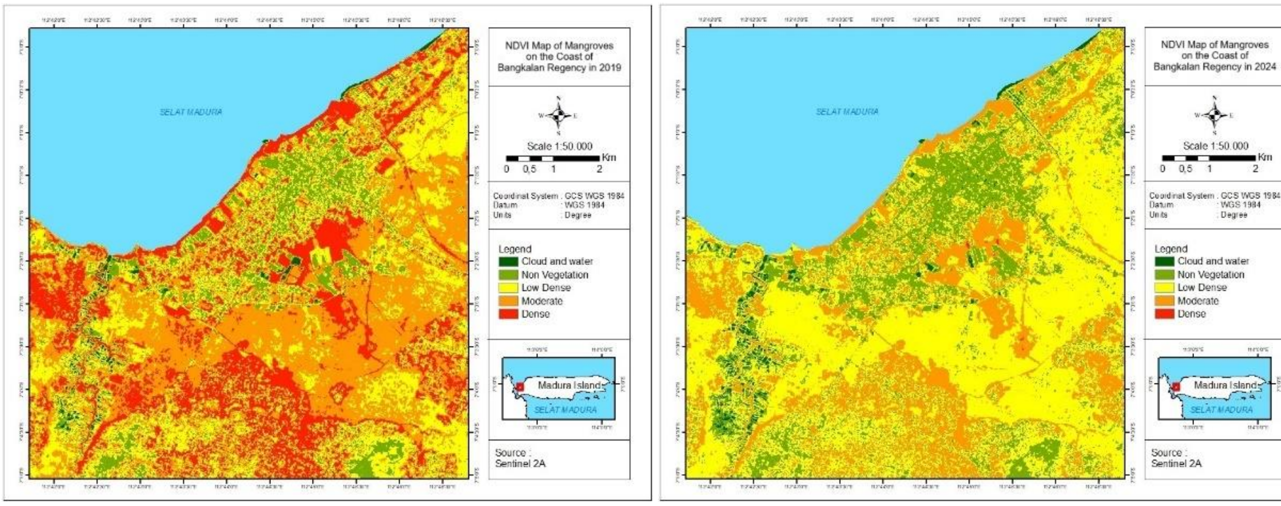

Figure 2. NDVI Map of Bangkalan Coast in 2019 and 2024

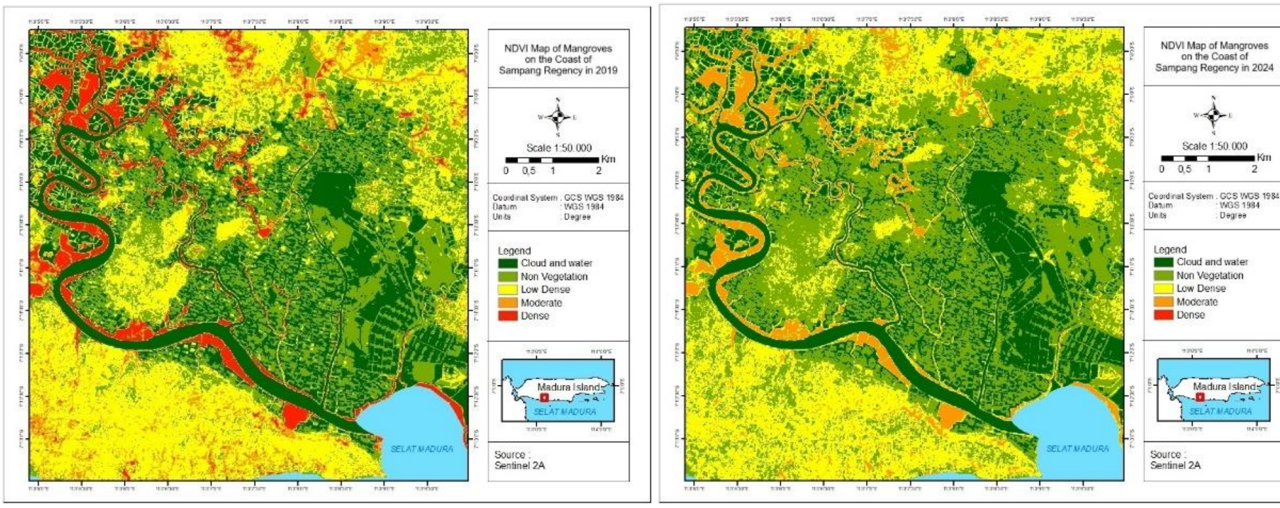

Figure 3. NDVI Map of Sampang Coast in 2019 and 2024

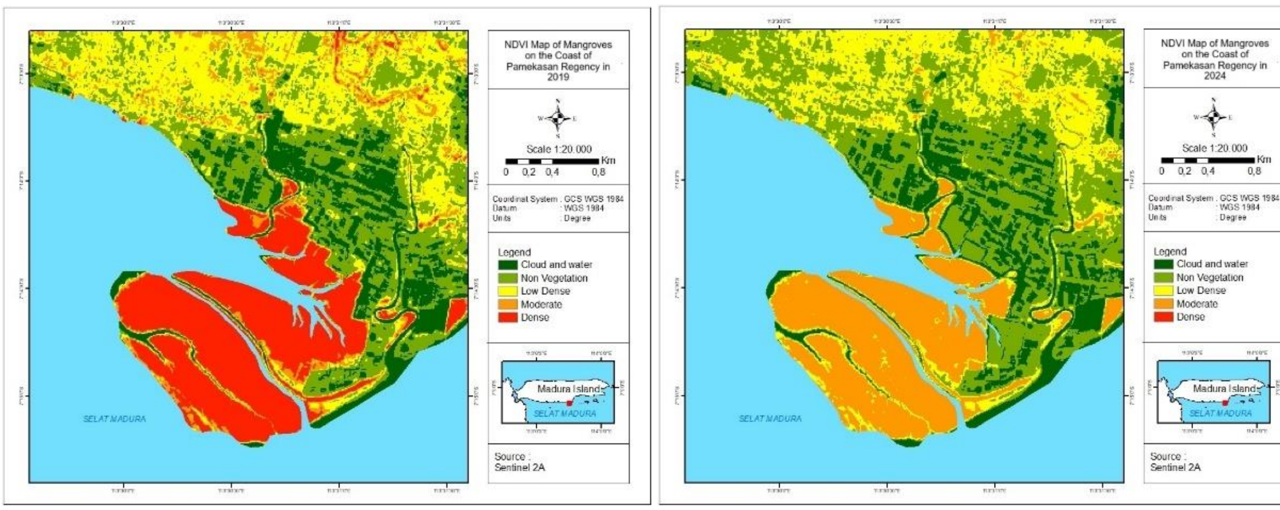

Figure 4. NDVI Map of Pamekasan Coast in 2019 and 2024

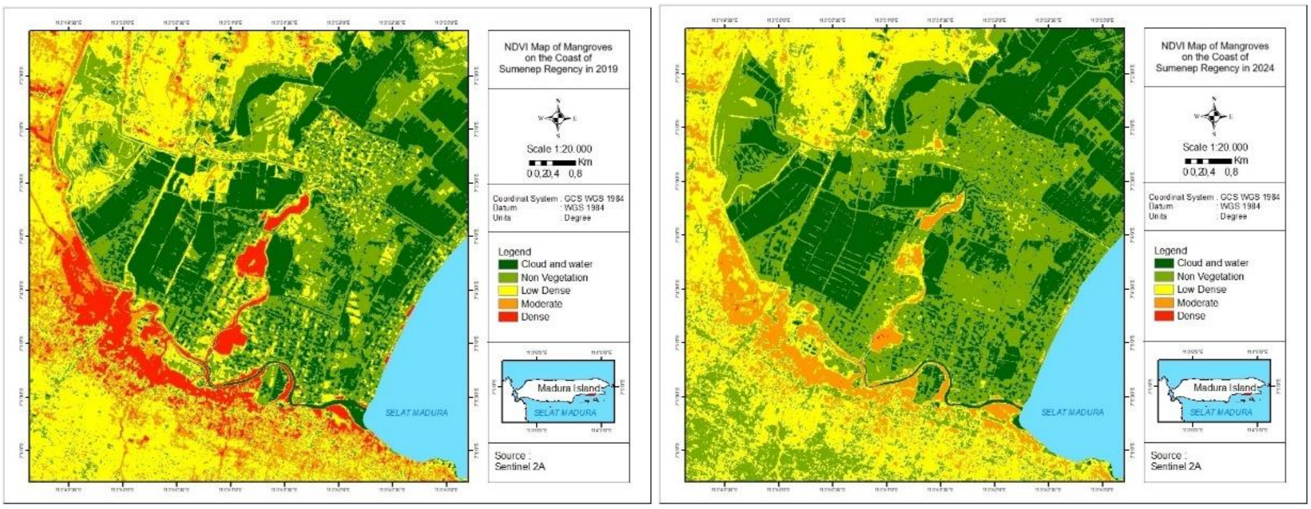

Figure 5. NDVI Map of Sumenep in 2019 and 2024

Table 3. Confusion matrix of classification results with field observation data

Mangrove density analysis	Ground truth						Producer's accuracy
	Cloud and water	Non vegetation	Low dense	Moderate	Dense	Total	
Cloud and water	21	0	2	0	0	23	91.3%
Non vegetation	2	5	3	0	1	11	45.5%
Low dense	2	0	0	2	1	5	0%
Moderate	0	0	0	0	0	0	0%
Dense	1	5	0	0	0	1	0%
Total	26	5	5	2	2	40	
Producer's accuracy	80.8%	100%	0%	0%	0%	70%	

Source: Kappa Analysis Results 2024

Table 4. Area (Ha) Analysis on the coasts of NDVI Classification in Bangkalan, Pamekasan, Sampang, and Sumenep

Mangrove density analysis	Locations							
	Bangkalan		Pamekasan		Sampang		Sumenep	
	2019	2024	2019	2024	2019	2024	2019	2024
Cloud and water	8.1	11.1	939.8	1,117.9	1,076.6	1,117.9	243.3	238.3
Non vegetation	52.7	10.7	1,241.0	1,319.9	1,169.0	1,319.9	140.9	299.1
Low dense	179.1	176.3	986.6	648.5	738.8	722.2	350.9	237.3
Moderate	348.9	355.3	305.4	409.3	882.5	759.3	254.1	235.1
Dense	114.7	150.1	61.8	39.2	464.6	412.3	154.3	133.8

Based on Table 4, it can be seen that in the Bangkalan area, the largest area is the mangrove region classified as moderately dense. In the Pamekasan area, the largest area is classified as non-vegetation, for example, houses, water, and vacant land. In the Sampang area, the largest area is also classified as non-vegetation. In the Sumenep area, the largest classification in 2019 was sparse vegetation, while by 2024, the largest area was classified as non-vegetated.

Discussion

2019 mangrove NDVI analysis

Mangrove areas in Madura are of significant coverage and play a crucial role in the coastal ecosystem. In 2019, the mangrove area in Madura was estimated to be declining by 1-2% per year, especially in regions under pressure from human activities (Iswahyudi et al. 2019). The total mangrove area in Madura reached 12,115.8 ha, distributed across various regions: Bangkalan with 1,508.1 ha (10%), Sampang with 915.3 ha (6,1%), Pamekasan with 599.3 ha (4%), and Sumenep, including its islands, with 12,095.4 ha (80%) (Muhsoni et al. 2019). Mangrove density in these regions can be influenced by several factors, including environmental conditions, human activities, and the mangrove species itself, such as the growth rate of mangroves and their natural regeneration ability. One of the key factors affecting mangrove density is the pressure from surrounding activities. Human activities, such as pollution from daily use, can adversely affect the environment and, in turn, influence the density of mangrove vegetation (Randa et al. 2020).

For example, salt pond activities often lead to the conversion of mangrove land into ponds, negatively impacting the density and diversity of mangrove species. This conversion reduces mangrove coverage, disrupts the ecosystem, and decreases mangrove density in the affected areas (Rachman 2024). Additionally, existing salt pond activities can cause pollution and changes in soil quality, further hindering the growth of mangrove plants (Duta 2020). Rehabilitation of land previously used as salt ponds, which is then abandoned, can contribute to the increase in density and diversity of mangrove species (Sakai 2023). The success of such rehabilitation efforts depends on effective management and public awareness of the importance of preserving mangrove ecosystems (Hardi et al. 2023).

Salt pond activities not only affect mangrove density but also have the potential to alter the structure of mangrove communities. For example, the increased nutrients derived from pond waste can influence the height distribution of mangrove plants, leading to conditions where mangroves compete with other vegetation (Armitage 2018). Conversely, such activities can also result in a decrease in species diversity (Sasmito et al. 2019). The relationship between salt pond activities and mangrove density on the coast of Madura is complex. While there is potential for rehabilitation of mangrove ecosystems, the challenges associated with managing salt ponds and maintaining sustainable mangrove density remain central concerns. Therefore, a sustainable and collaborative approach among stakeholders is crucial for ensuring the long-term health and growth of mangrove populations (Arifanti 2024). Clearing land for agriculture and plantations, such as oil palm, banana, and fish ponds, is one of the primary causes of mangrove loss. These activities often lead to the removal of mangroves and disrupt the ecological functions of the land.

Mangrove density in a region can vary, indicating that local factors influence this variation (Hasidu et al. 2021). The condition of mangrove land in Madura in 2019 was dense. This was due to factors such as species distribution, environmental conditions, soil quality, and mangrove management. The species distribution factor reveals that the presence of adaptive mangrove species, such as *R. mucronate* and *A. marina*, contributed to the increased density of the mangrove ecosystem (Tufliha et al. 2019). Additionally, environmental factors such as salinity and soil quality significantly impact the mangrove ecosystem and affect the growth of mangrove vegetation. Proper salinity conditions in a mangrove ecosystem are crucial for supporting mangrove growth (Matatula 2019). Furthermore, effective management of the mangrove ecosystem helps maintain the health of mangrove vegetation, which in turn influences the increase in mangrove ecosystem density (Adinegoro et al. 2022).

Mangrove vegetation in Madura includes several species that dominate the regions of Bangkalan, Sampang, Pamekasan, and Sumenep, such as *R. mucronata*, *A. marina*, and *Sonneratia alba*, which are commonly found species (Hamzah et al. 2021). In the Bangkalan region, *R. mucronata* was identified as the dominant species and grew well. In the Sampang and Pamekasan regions, *A. marina* became the dominant species in the mangrove ecosystem (Hamzah et al. 2021). In the Sumenep coastal area, the same species as those in the other three regions were also found. The variation in mangrove vegetation density is influenced by environmental conditions and the mangrove land management practices applied in each region (Febrianto et al. 2022).

The distribution of mangrove species in each region shows that *Rhizophora* and *Avicennia* species dominate, which is consistent with findings of mangrove species in other locations (Suryono et al. 2020). Different mangrove species exhibit varying densities and distributions, which are influenced by environmental conditions and management practices (Mardliyah et al. 2019). The interpretation of mangrove land in Madura, particularly in the regions of Bangkalan, Sampang, Pamekasan, and Sumenep, indicates that the ecosystem has a high density. However, the health of the mangrove ecosystem needs to be monitored. The health of mangrove vegetation in an ecosystem can be categorized based on the density and structure of the stands (Azzahra et al. 2023). A mangrove health assessment can be conducted by analyzing mangrove density through satellite imagery, such as NDVI, to assess canopy cover and overall ecosystem health (Tanjung et al. 2022). High mangrove density can indicate a healthy mangrove ecosystem. Increased mangrove density leads to higher litter production, generating more detritus and nutrients, thereby supporting the abundance of macro zoobenthos as a food source and attracting more benthic fauna to inhabit the ecosystem (Arfan et al. 2023).

Analysis of mangrove NDVI 2024

The coast of Madura is home to mangrove species such as *A. marina*, *R. stylosa*, and *S. alba*. In the Bangkalan coastal area, several mangrove species, such as *Avicennia alba*, *Avicennia lanata*, *Sonneratia caseolaris*, *Xylocarpus granatum*, and others, are found (Hur et al. 2020). Suitable environmental conditions support the growth of these mangrove species. *Avicennia marina* is known for its high tolerance to salinity and its respiratory roots, which enable gas exchange in anaerobic conditions on muddy substrates. *Rhizophora stylosa* thrives in muddy substrates, which are commonly found along the Madura coast. Additionally, *R. stylosa* can survive in areas with high water inundation and relatively strong currents. Its stilt root system provides stability in muddy substrates. *Sonneratia alba* is more adaptable to sandy or mixed sandy-muddy substrates, allowing it to grow well along the Madura Strait coast, where water currents bring nutrients. Its respiratory roots enable it to survive in harder substrates.

However, there has been a decline in mangrove density since 2019. This decline could be attributed to various interests of the local community, including settlement, fisheries, ports, and other activities in the area (Wardhani 2014). Dense mangrove distribution was observed along the coasts of Bangkalan, Sampang, Pamekasan, and the central area of Sumenep in 2024. The dense class is typically dominated by tree species, as the trees are relatively spaced apart (Pratama 2017). A decrease in mangrove density was also noted in other study locations, such as the coasts of Sampang, Pamekasan, and Sumenep. Anthropogenic activities may contribute to the decline in mangrove density in Sumenep. The Kalianget waters in Sumenep, located at the eastern tip of Madura Island, are used as a port area to support inter-island crossings and fishing activities.

In the coastal areas of the region, the local community has engaged in significant development activities, including land reclamation and mangrove tree cutting. These actions were taken to build salt ponds, shrimp ponds, and ports. Human activities around the waters, combined with the effects of hydro-oceanographic processes, can affect the properties, sediment distribution patterns, and shoreline changes (Nuraine et al. 2021). Mangroves on the coast of Madura grow in areas with high salinity, largely due to intensive salt pond activities. This high salinity influences the light reflection spectrum of the vegetation, resulting in lower NDVI values compared to mangroves in ecosystems less affected by extreme salinity. The expansion of salt ponds and shrimp ponds has led to mangrove fragmentation, creating uneven NDVI patterns. Areas with healthy mangroves show high NDVI values (>0.6), while degraded areas show low values (<0.3).

The mangrove ecosystem in Sampang is generally found along the coastal areas, forming a green belt. Two mangrove species dominate the region of Sampang, Madura, *Rhizophora apiculata* and *S. alba*, with trees that are not very tall. Sampang and Pamekasan are part of the coastal area, crossed by the South Coast Road. This road often experiences tidal flooding, which can affect the mangrove ecosystem in the area. Additionally, there are abiotic factors that can influence the reduction in mangrove density in Sampang and Pamekasan, such as salinity, air temperature, water pH, soil pH, rainfall, and light intensity. The Sampang area has muddy characteristics, as it faces directly toward the coast. *Sonneratia alba* is the outermost species in the region. Mangrove areas in Pamekasan have experienced a decline in density due to the large amount of plastic waste discarded by local communities, and some mangrove plants have died as a result of being cut down by the people (Lathifah et al. 2024).

Analysis of mangrove area changes in 2019 and 2024

Based on Table 4, the mangrove area in Bangkalan, Pamekasan, Sampang, and Sumenep in 2019 and 2024 has experienced both increases and decreases. The increase in mangrove area is evident in the coastal area of Bangkalan, where the moderately dense classification increased from 348.9 ha in 2019 to 355.3 ha in 2024, and the dense category increased from 114.7 ha in 2019 to 150.1 ha in 2024. The expansion of the mangrove area also occurred in the coastal area of Pamekasan, where the moderately dense classification increased from 305.4 ha in 2019 to 409.3 ha in 2024. This increase in mangrove area can be attributed to tidal changes that affect the nutrients brought along, causing mangrove vegetation near the sea or facing the sea to expand (Wilujeng et al. 2022). Another contributing factor is sedimentation. The muddy type of sedimentation, rich in organic material, supports the healthy growth of mangroves, thus increasing the size of the mangrove area. The expansion of mangrove areas along these coastlines helps stabilize the shore and prevent coastal erosion. As the area and size of mangroves increase, so do their benefits, adding value to the mangrove ecosystems in the area (As'adi et al. 2023). However, despite the growth in some areas, this increase does not compensate for the areas where mangrove coverage has decreased.

The decrease in mangrove area is more dominant compared to the increase in mangrove area (Table 4). The mangrove area in the coastal region of Madura may decrease due to both natural and anthropogenic factors. Natural factors include currents, tidal waves, and weather changes that can damage mangroves. Human-induced factors involve land conversion for various purposes, such as settlements, salt ponds, or other uses like agriculture, aquaculture, or industrial development. The Madura coast is recognized as one of the national centers for salt production (Syakatera and Purnomo 2022). The reduction of mangrove areas due to such conversions has negative environmental impacts. Ecologically, the conversion of mangrove areas leads to a decrease in ecological functions in the region. The impacts that may occur include coastal abrasion, which can cause land loss and affect shoreline changes (Zainuri et al. 2017). Furthermore, the conversion or reduction of mangrove areas can also affect the economic condition of coastal communities, as the natural resources that provide their livelihoods-such as the economic value of mangroves, mangrove crabs, shrimp, fish, etc.-are diminished (Hafni 2020).

Kappa accuracy test

The accuracy test using the kappa coefficient is frequently used to evaluate the accuracy of spatial data classification, including satellite image analysis to assess mangrove density based on vegetation indices such as NDVI (Verma et al. 2020). Kappa analysis is conducted by comparing the multispectral classification results from satellite imagery with existing field conditions to produce valid values (Wang et al. 2018). A high kappa accuracy value indicates good classification results, meaning the produced map can be used for planning and managing mangrove areas. According to the Head of the Geospatial Information Agency (BIG) Regulation No. 15 of 2014 on Technical Guidelines for Map Accuracy, the results must have an overall accuracy of ≥85% to be considered a good classification result. According to LAPAN (2015), the classification accuracy level should be ≥75%. The kappa accuracy test results in this study show a value of 70% (Table 3), which does not meet the requirements set by BIG Regulation No. 15 of 2014 (≥85%) or LAPAN USGS (≥75%). This is consistent with the research by Gumma et al. (2019), which states that accuracy values greater than 70% are considered acceptable. In contrast, the study by Mappiasse et al. (2022) on mangrove distribution in Maros in 2021 achieved an accuracy value of 86.67%. In this study, field observations on the health of mangrove forests showed a relatively high degree of agreement.

NDVI classification has weaknesses in determining the range of modes (minimum and maximum), which can lead to errors. The overlapping values make interpretation difficult, resulting in lower accuracy (Indarto et al. 2020). Significant changes in vegetation density or land cover over a short period pose a particular challenge, as the values at the Ground Control Points (GCP) may not remain constant throughout the analyzed period (Ruan et al. 2022). The accuracy value produced is related to omission error, which refers to the failure to represent objects present in the field on the map. Conversely, user accuracy is related to commission error, which occurs when objects shown on the map are not actually found in the field (Putri and Widayani 2018).

In addition to technical factors such as weather, cloud cover, and image quality, human error can also influence the NDVI Kappa accuracy calculation. Human error may occur during field data collection (ground truth), such as when the location is not representative or measurements are inconsistent (Rawson et al. 2022). Errors during the analysis phase, such as data input and calculations, should also be considered. According to Indarto et al. (2020), directly using NDVI values for classification processes is not recommended. A more comprehensive study of characteristics and specific timeframes (month or year) is needed to represent better land use variation in the field (Kurniawan and Ramadhan 2024). Mitigation measures to address these issues may include standardizing procedures with clear guidelines, conducting training and validation, and incorporating automation technologies for improved efficiency

Challenges and recommendations

Many efforts are needed to manage mangroves to maintain the sustainability of the mangrove ecosystem and ensure it functions properly. The challenges faced by mangrove ecosystems, particularly in the Madura region, are significant. One of the main challenges is land conversion for agricultural purposes and infrastructure development. The expansion of these sectors can lead to the destruction of the mangrove ecosystem (Jabbar et al. 2021). Other challenges include climate change and increased human activity, such as the use of environmentally harmful fishing practices and pollution, which negatively affect the quality and extent of mangrove areas (Adrian 2023). Improper mangrove land management can result in the loss of the ecosystem's functions, including its role in coastal protection and as a habitat for various species (Sarastika 2021).

Sustainable management strategies are essential to address future challenges and ensure the long-term health of mangrove ecosystems, particularly in the Bangkalan, Sampang, Pamekasan, and Sumenep regions. Key actions that can be taken include replanting mangroves, regulating land use, and raising public awareness about the importance of mangrove ecosystems (Arkham 2023). Through these efforts, it is hoped that the mangrove areas in these regions will remain sustainable and continue to provide benefits to the local communities.

The mangrove conservation and rehabilitation program, which includes planting activities, has been widely implemented in various regions across Indonesia and has become a government priority since 2020. This initiative is driven by the numerous benefits provided by mangrove ecosystems, including provisioning services (such as fish, clean water, and wood), regulating services (such as climate control, water purification, and disease regulation), cultural services (such as spiritual, recreational, educational, and aesthetic values), and supporting services (such as nutrient cycling, soil formation, and habitat support) (Kurniawan et al. 2024). In the research area, three key concepts- education, conservation, and community empowerment-can be adapted through appropriate environmental communication strategies. These strategies aim to ensure that the managed areas are further developed by designing activities that address the specific problems faced by local communities (Pratama 2024). Additionally, collaboration between district and provincial governments, in line with the implementation of Law No. 1 of 2014 and Law No. 23 of 2014, is crucial for promoting sustainable development, particularly in Bangkalan (Rosyid et al. 2021).

In conclusion, the mangrove areas along the coast of Madura Island from 2019 to 2024 showed some increase in mangrove cover, particularly along Bangkalan coastline. The moderately dense category increased from 348.9 ha in 2019 to 355.3 ha in 2024, while the dense category grew from 114.7 ha in 2019 to 150.1 ha in 2024. Similarly, Pamekasan coastline saw an increase in the moderately dense category, from 305.4 ha in 2019 to 409.3 ha in 2024. However, the reduction in mangrove area outweighed the increase in coverage. This decline can be attributed to factors such as climate anomalies and the conversion of mangrove land for purposes like settlements or salt ponds, which pose challenges for mangrove management in Madura. The overall Kappa accuracy result was 70%, indicating lower accuracy, with 14 out of 40 points showing discrepancies. Factors influencing this accuracy include technical aspects related to image data, such as weather conditions, cloud cover, image quality, and human error. Efforts to preserve mangrove forests in Madura should focus on improving education, conservation initiatives, and community empowerment, utilizing sustainable environmental communication strategies.

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INDO PAC J OCEAN LIFE
Volume 8, Number 2, December 2024
Pages: 112-121

P-ISSN: 2775-1961
E-ISSN: 2775-1953
DOI: 10.13057/oceanlife/o080206

Structure and composition of Ophiuroidea (Echinodermata) at three beaches in Gunungkidul, Yogyakarta, Indonesia

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Manuscript received: 31 March 2024. Revision accepted: 31 December 2024.

Abstract. *Yap CK, Putri RRA, Manullang RH, Andrianto R, Salsabila S, Nugroho GD, Setyawan AD. 2024. Structure and composition of Ophiuroidea (Echinodermata) at three beaches in Gunungkidul, Yogyakarta, Indonesia. Indo Pac J Ocean Life 8: 112-121.* Ophiuroidea (Echinodermata) contribute significantly to species diversity, abundance, and biomass of the world's marine fauna. The study aimed to determine the composition structure of Ophiuroidea in the coastal area of Gunungkidul, Yogyakarta, Indonesia. It was conducted in March 2024 at Pringjono Beach, Torohudan Beach, and Dadap Ayam Beach, at low tide with a sampling area of about 1,000 m^2 on each beach. We recorded the name of the species, the number of individuals, and description of visible characteristics as well as pH, Dissolved Oxygen (DO), and seawater temperature. The data were analyzed using the density, Shannon-Wiener diversity index (H'), evenness index (E), and richness index (R). We found five species from two families, Ophiocomidae, with *Breviturma dentata* (Müller and Troschel, 1842); *Ophiocoma schoenleinii* (Müller and Troschel, 1842); *Ophiocoma scolopendrina* (Lamarck, 1816); *Ophiocoma erinaceus* (Müller and Troschel, 1842); and Ophiomyxidae, with only one species, *Ophiarachna affinis* (Lütken, 1869). *Breviturma dentata* was the most dominant species, with 495 individuals. Pringjono Beach had the highest density, followed by Torohudan Beach and Dadap Ayam Beach. Then, for H' and E were low, but R was moderate. Water temperature, pH, and DO may affect species density in these areas.

Keywords: Echinodermata, ecosystem, environment, Gunungkidul, Ophiuroidea

INTRODUCTION

Indonesia is an archipelago that is rich in biological resources, this can be seen from the diversity of marine biota (Hasan et al. 2023; Helmiyani et al. 2024). One example of the diversity of marine life in Indonesia is Echinodermata (Nurcahyo et al. 2024; Mustagfirin et al. 2021; Horman et al. 2024; Rindriawaty et al. 2025), especially the Ophiuroidea class. The presence of Echinodermata can be an indicator in determining the balance of marine ecosystems (Hermosillo-Núñez 2020; Patech et al. 2021). In general, Echinodermata reach their highest diversity on coral reefs and shallow beaches because their larvae are pelagic and swim long distances to expand their distribution (Deaker and Byrne 2022; Pereira and Pardal 2024). Echinodermata habitats are influenced by physical and chemical factors (Lawrence 2020; Lestari et al. 2020). These factors include substrate conditions, water quality, and the presence of predators and competitors in the surrounding environment (South et al. 2022).

The Ophiuroidea class is one of the two most species-rich Echinodermata classes (Lessios and Hendler 2022). The Ophiuroidea class is usually found around soft sediments, rocks, corals, sponges, sand, macroalgae, and dead corals (Suwartimah et al. 2017; Nugroho et al. 2018). These habitats provide shelter and food for Ophiuroidea species, allowing them to survive and reproduce. Ophiuroidea distribution diversity can be influenced by environmental factors such as temperature, light, and substrate characteristics (Post et al. 2017). Interactions between these factors often create conditions that favor the survival of different species in different ecosystems.

Echinodermata in Indonesia can be classified into about 1,600 species (Ringvold et al. 2021). A wide variety of Echinodermata species are found in Indonesia, a country that has high biodiversity as it is located at the center of the world's coral regions (Anahau and Ina 2023). Indonesia's strategic position provides ecological benefits in the form of access to global marine biota distribution pathways. The distribution of Echinodermata species is most commonly found on the beaches in Gunungkidul, especially Ophiuroidea species. This is influenced by favorable environmental factors such as water temperature, Dissolved Oxygen (DO), and water pH (Lopo et al. 2023). These stable environmental conditions are the main reason why the area is a favorite habitat for Ophiuroidea. The beaches in Gunungkidul have characteristics of rocky shores, which are suitable as a habitat for Ophiuroidea, which is one of the typical living creatures of rocky shores (Nugroho et al. 2018). According to Buyami et al. (2020), Ophiuroidea is also found on beaches that have tidal zones, such as the beaches in Gunungkidul. This zone provides dynamic conditions that allow organisms to adapt to environmental changes.

Research on Echinodermata, especially Ophiuroidea in Gunungkidul beaches, has been conducted previously in various locations, such as in the waters of Krakal Beach (Suwartimah et al. 2017), Indrayanti Beach (Nugroho et al. 2018), and Watu Kodok Beach (Tarigan et al. 2020). This research was conducted because the location taken was different from previous studies. This effort aims to complement biodiversity data that has not been thoroughly documented. The beaches are remote and difficult to reach (Nurzaman et al. 2020), making it difficult for researchers to carry the necessary equipment and logistics (Natalia et al. 2020). Another reason is the lack of understanding of the biodiversity, ecology and role of Ophiuroidea in marine ecosystems (Suprapto et al. 2022). In addition, the lack of research on Ophiuroidea in Gunungkidul can also be caused by several factors, including limited resources, lack of researcher interest, or a focus on other species that are considered more important or better known scientifically. However, it is important to remember that each species has a specific role in its ecosystem, including Ophiuroidea. As a result, knowledge of Echinodermata (Ophiuroidea) populations in this region still needs to be improved (Pakpahan et al. 2020). Every ecosystem is unique and interesting to study (Bohnsack et al. 2024). Such ecosystem studies not only provide scientific insights but also contribute to better conservation efforts. The purpose of this study is to determine the composition structure of Echinodermata (Ophiuroidea) in Gunungkidul, namely Pringjono Beach, Torohudan Beach, and Dadap Ayam Beach, Kanigoro Village, Saptosari Sub-district, Gunungkidul, Yogyakarta, Indonesia.

MATERIALS AND METHODS

Study area

Sampling was conducted in March 2024 at Pringjono Beach, Torohudan Beach, and Dadap Ayam Beach, Kanigoro Village, Saptosari Sub-district, Gunungkidul District, Yogyakarta, Indonesia (Figures 1 and 2). Pringjono Beach is located at 8°07'03"S 110°29'57"E, Torohudan Beach at 8°07'20"S 110°30'58"E, and Dadap Ayam Beach at 8°07'13"S 110°30'26"E (Figures 2.A-C; Table 1). Gunungkidul's extraordinary natural beauty is defined by its unique karst landscapes, limestone formations, and extensive cave systems. The region boasts rich biodiversity with rare and endemic species, and features unique hydrological elements like underground rivers and springs. Its distinctive climate shapes the ecosystem, while striking topography includes hills, valleys, and coastal cliffs. Gunungkidul, geographically bordered by Sleman District to the north, the Indian Ocean to the south, Wonogiri District to the east, and Bantul District to the west, exhibits significant natural attractions. These geographic and environmental features contribute to its appeal as a tourist destination, drawing visitors from various regions (Fujiwara et al. 2018).

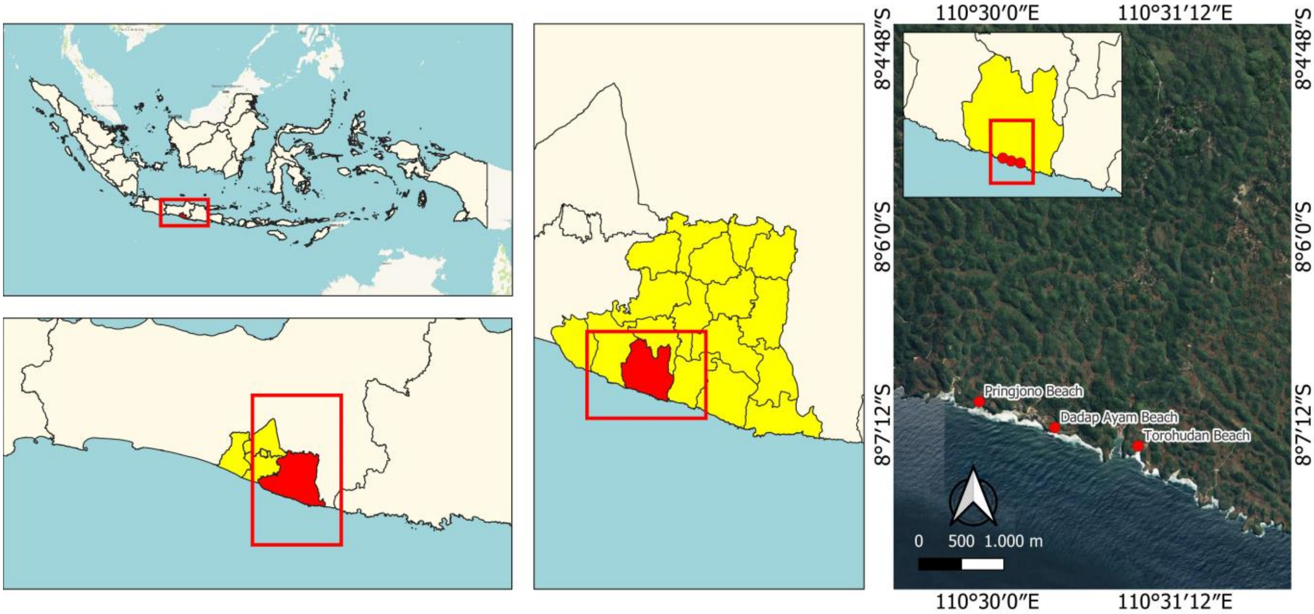

Figure 1. Map of the research location. The research locations were Pringjono Beach, Torohudan Beach, and Dadap Ayam Beach, Kanigoro Village, Saptosari Sub-district, Gunungkidul District, Yogyakarta, Indonesia

Figure 2. Echinodermata (Ophiuroidea) sampling areas: A. Pringjono Beach, B. Torohudan Beach, and C. Dadap Ayam Beach, Kanigoro Village, Saptosari Sub-district, Gunungkidul District, Yogyakarta, Indonesia

Table 1. Location of beach administration

Beach	Coordinates	Administrative location
Pringjono Beach	-8° 7' 4.306" S, 110° 29' 58.146" E	Kanigoro Village, Saptosari District, Gunung Kidul District, Yogyakarta Province, Indonesia
Torohudan Beach	8° 7' 21.226" S, 110° 30' 58.666" E	Kanigoro Village, Saptosari District, Gunung Kidul District, Yogyakarta Province, Indonesia
Dadap Ayam Beach	-8° 7' 13.738" S, 110° 30' 26.809" E	Kanigoro Village, Saptosari District, Gunung Kidul District, Yogyakarta Province, Indonesia

Pringjono Beach has a wide shoreline of soft white sand and is surrounded by coral cliffs formed from andesite and limestone rocks, creating an ideal habitat for a variety of marine species, including the snaking star that is often found among the corals. Torohudan Beach, characterized by steep cliffs and more rugged coral formations, provides rich biodiversity and shelter for fish and marine invertebrates. Dadap Ayam Beach, on the other hand, is known for its more gently sloping and wide beaches, and the presence of more lush coastal vegetation, creating an ecosystem that supports shorebirds and other organisms. The main difference lies in the geologic structure; Pringjono with flat corals, Torohudan with steep cliffs, and Dadap Ayam with a more visitor-friendly sloping beach. All three sites serve as important habitats for the snaking star, which utilizes the crevices between the rocks to hide from predators and find food.

Data collection

Ophiuroidea diversity was observed physically at low tide in a sampling area of about 1,000 m^2 on each beach (Aulia et al. 2021). Sampling, and data collection were carried out in the plot. The sampling procedure involved walking along the beach at low tide, starting from the sandy shore and extending to the farthest observable boundary about 1,000 m^2, employing direct observation. Data collected consisted of the number of Ophiuroidea species found directly in the field, as well as measuring water abiotic factors such as pH, temperature, and Dissolved Oxygen (DO) at each location. Each specimen collected on the beach was counted and documented. The identification of Ophiuroidea was conducted by considering terminology, species, and genus levels (Suwartimah et al. 2017; Setiawan et al. 2019; Tarigan et al. 2020; Tavares et al. 2021).

Data analysis

The data obtained were analyzed using density, diversity index, evenness index, and richness index. Then, value ranges and categories for each index can be seen in Table 2.

Density

Density is the density or number of individuals of a species per unit area (Setiawan et al. 2018). The density formula can be written as follows:

$$Density\ (K) = \frac{number\ of\ individuals}{plot\ area}$$

Shannon Wiener diversity index (H')

The diversity index is a measurement used to calculate the magnitude of species diversity in sampling (Azhari et al. 2018). The diversity index used is the Shannon-Wiener index using the formula:

$$H' = -\Sigma pi \times \ln pi$$

Where:
H': Diversity index
pi: Relative abundance of species
ln: Natural logarithm

Table 2. Value range and categories of diversity, evenness, and richness indices

Index	Value range	Category
Diversity (H')	H'<1.0	Low
	1.0<H'<3.0	Medium
	H'> 3.0	High
Evenness (E)	0.00<E<0.50	Low
	0.50<E<0.75	Medium
	0.75<R<1.00	High
Richness (R)	0.00<R<0.50	Low
	0.50<E<0.75	Medium
	0.75<R<1.00	High

Evenness index (E)

The evenness index describes the number of individuals between species in an invertebrate community (Pertiwi et al. 2020). The more even the distribution of individuals between species, the more ecosystem balance increases. The evenness index was analyzed using the following index:

$$E = H'/\ln S$$

Where:
E: Evenness index
H': Diversity index
ln S: Number of species with E values ranging from 0-1

Richness index (R)

Richness index is a measure of species richness that depends on the direct relationship between the number of species and the logarithm of the sampling area (Dewi et al. 2023). The richness index used is the Margalef richness index with the formula:

$$R = (S-1)/(\ln(N))$$

Where:
R: Richness index
S: Total number of species
N: Total number of individual

RESULTS AND DISCUSSION

This study found five species from to families, Ophiocomidae and Ophiomyxidae, each displaying unique characteristics and adaptations that enable them to thrive in diverse marine environments (Tables 3; Figure 4). The most dominant family is Ophiocomidae, with the species *Breviturma dentata* (Müller and Troschel, 1842), *Ophiocoma schoenleinii* (Müller and Troschel, 1842), *O. scolopendrina* (Lamarck, 1816), and *O. erinaceus* (Müller and Troschel, 1842). The Ophiomyxidae family is represented by only one species, *Ophiarachna affinis* (Lütken, 1869).

In Table 3, one class was found to be distributed across all three beaches: Ophiuroidea, with a total of five identified species. The species within the class Ophiuroidea: *B. dentata*; *O. schoenleinii*; *O. scolopendrina*; *O. erinaceus*; and *O. affinis* (Figure 3). The Echinodermata identified in this study consist of five species from two families: Ophiocomidae and Ophiomyxidae. The most dominant from three beachs is *B. dentata* with 495 individuals and the lowest density is *O. scolopendrina* with 7 individuals.

Table 3. Echinodermata (Ophiuroidea) species are found in Pringjono Beach, Torohudan Beach, and Dadap Ayam Beach, Kanigoro Village, Saptosari Sub-district, Gunungkidul District, Yogyakarta, Indonesia

Family	Species	Density (ind/1,000m^2)
Ophiocomidae	*Breviturma dentata* (Müller and Troschel, 1842)	495/1,000m^2
Ophiocomidae	*Ophiocoma schoenleinii* (Müller and Troschel, 1842)	71/1,000m^2
Ophiocomidae	*Ophiocoma scolopendrina* (Lamarck, 1816)	7/1,000m^2
Ophiocomidae	*Ophiocoma erinaceus* (Müller and Troschel, 1842)	55/1,000m^2
Ophiomyxidae	*Ophiarachna affinis* (Lütken, 1869)	21/1,000m^2

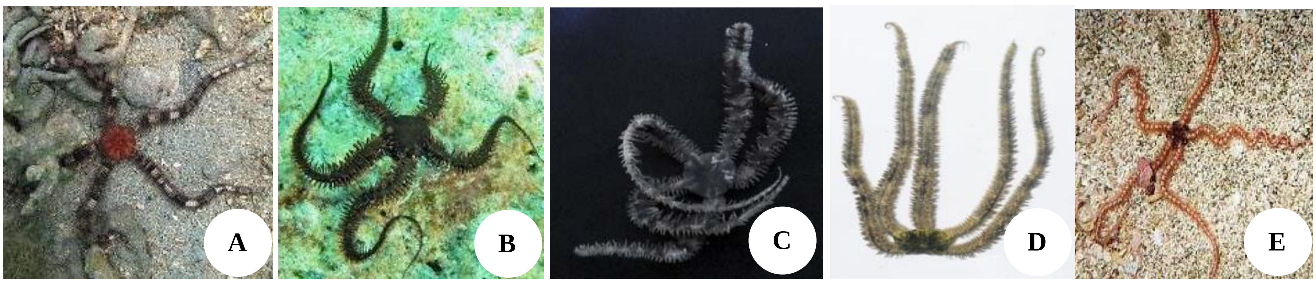

Figure 3. Echinodermata (Ophiuroidea) in this research: A. *Breviturma dentata* (Source: Luthfi 2021); B. *Ophiocoma schoenleinii* (Source: Lesawengan et al. 2019); C. *O. erinaceus* (Source: Triana et al. 2015); D. *O. scolopendrina* (Source: Setiawan et al. 2019); E. *Ophiarachna affinis* (Source: Suwartimah et al. 2017)

The calculation results of the ecological index are grouped into three categories: diversity index, evenness index, and species richness index. In Table 4, the analysis results indicate that the diversity levels at the three beaches are relatively low. The diversity index values for each beach are as follows: Pringjono Beach is 0.63, Torohudan Beach is 0.57, and Dadap Ayam Beach is 0.74. Furthermore, in Table 5, the analysis results reveal that the evenness levels at the three beaches are also relatively low. The evenness index values for each beach are: Pringjono Beach is 0.46, Torohudan Beach is 0.43, and Dadap Ayam Beach is 0.41. Additionally, based on Table 6, the three beaches exhibit moderate species richness levels. The species richness index values in Pringjono Beach is 0.52, Torohudan Beach is 0.55, and Dadap Ayam Beach is 0.66, respectively.

In Table 7, the research locations at the three beaches included measurements of several abiotic environmental parameters based on the diversity of brittle stars. The results of this study were obtained through measurements of water temperature, pH, and Dissolved Oxygen (DO) at the three beaches serving as research sites. The water temperature measurements at the three beach locations showed the following results: Pringjono had a water temperature of 27-30.8°C, Torohudan recorded 28-30.3°C, and Dadap Ayam measured 28-30.1°C. Next, the pH measurements at the sampling locations were as follows: 6.98-7.92 at Pringjono, 8.26-8.55 at Torohudan, and 8.26-8.38 at Pantai Dadap Ayam. The DO measurements for the samples were 0.70-2.31 mg/L at Pringjono, 0.30-0.49 mg/L at Torohudan, and 0.49-1.70 mg/L at Dadap Ayam. The measurements of these abiotic environmental parameters were conducted using appropriate tools for each parameter being measured.

Discussion

Species found

The species *B. dentata* is distinguished by its circular disc shape, which is dorsally flattened and covered with small, rounded granules that obscure the underlying scales and radial shields (Pillai and Biju Kumar 2019). According to Setiawan et al. (2018), *B. dentata* is found in tropical and subtropical waters around the world and is known for its ability to inhabit a variety of habitats, ranging from coral reefs to rocky shores (O’Hara et al. 2019). The species *O. schoenleinii* has unique morphological characteristics, including a distinctive pattern of spines on its body. *Ophiocoma schoenleinii* species is found in the Indo-Pacific region and is known for its ability to inhabit deep sea environments. The species *O. scolopendrina* is characterized by its dark dorsal body and light ventral body (Biserova et al. 2023). This species is known for its ability to inhabit crevices or beneath the margins of intertidal reef platforms. *Ophiocoma scolopendrina* can also reproduce throughout the year and is known to have a symbiotic relationship with other organisms The habitat of *O. scolopendrina* is restricted to intertidal environments in the Indo-Pacific (Triacha et al. 2021). Like *O. scolopendrina, O. erinaceus* species are also found in tropical and subtropical waters. The species *O. erinaceus* may have a unique way of gathering food and reproducing. *Ophiocoma erinaceus* has a unique way of collecting food by using its long, slender arms equipped with cilia to capture food particles from the surface of the substrate (Byrne et al. 2024). In addition, *O. erinaceus* prefers habitats with bottom substrates of mixed mud and fine sand (Nurdiansah and Supono 2017). The family Ophiomyxidae is represented by one species, *O. affinis*, which is characterized by its unique body shape and is longer than other species in this class. The species *O. affinis* is found in the tropical and subtropical waters, especially in the Indian Ocean and western Pacific Ocean. This species usually lives on coral reefs, rocky bottoms, and sometimes in sandy areas at varying depths (Lawere et al. 2023). They often hide in rock crevices or under coral during the day and become more active at night.

Table 4. Diversity index (H')

Location	Diversity index value (H')	Category
Pringjono Beach	0.63	Low
Torohudan Beach	0.57	Low
Dadap Ayam Beach	0.74	Low
Total	0.24	Low

Table 5. Evenness index (E)

Location	Evenness index (E)	Category
Pringjono Beach	0.46	Low
Torohudan Beach	0.43	Low
Dadap Ayam Beach	0.41	Low
Total	0.15	Low

Table 6. Richness Index (R)

Location	Richness index (R)	Category
Pringjono Beach	0.52	Medium
Torohudan Beach	0.55	Medium
Dadap Ayam Beach	0.66	Medium
Total	0.62	Medium

Table 7. Environmental parameter results

Location	Water temperature (°C)	pH of water	DO water (mg/L)
Pringjono Beach	27-30.8	6.98-7.92	0.70-2.31
Torohudan Beach	28-30.3	8.26-8.55	0.30-0.49
Dadap Ayam Beach	28-30.1	8.26-8.38	0.49-1.70

Species density

The highest number of individuals per 1,000 m^2 was *B. dentata*, with 495 individuals per 1,000 m^2, while *O. scolopendrina* had the lowest, with seven individuals per 1,000 m^2. Factors such as water temperature, and water quality are known to affect the health and survival of Ophiuroidea, thus explaining the low number of individuals on the three beaches. Although starfish do not have many well-defined sense organs, they are sensitive to touch, light, temperature, orientation, and the status of the water around them (Rahman et al. 2018). Density also affects the physical and chemical properties of materials and has important implications in various materials applications. Species density is obtained by counting the number of individuals of a species present in a given area, usually in units such as hectares, and dividing it by the area. Species density in a given area can vary based on its locational conditions (Pretzsch and del Río 2020). Species density and the number of species in a plot are of a fixed size and will increase with the total habitat area in the local landscape surrounding the plot (Watling et al. 2020).

Morphology description (Figure 3)

Breviturma dentata (Müller and Troschel, 1842) (Figure 3.A)

The body of *B. dentata* is flat and round, featuring five long and slender arms. The central disk measures between 1 to 2 cm in diameter, while the arms can extend up to 10 cm in length. The color ranges from light brown to black, often adorned with spots or stripes. Its surface is rough, entirely covered with short, blunt spines. *Breviturma dentata* exhibits radial pentamerous symmetry similar to that of a typical starfish, but with a harder texture. This hardness is due to the presence of calcareous plates containing calcium carbonate and magnesium carbonate, making its texture more rigid compared to that of a regular starfish. The pentamerous radial symmetry is clearly visible, with sharp grooves between the five parts, ensuring that damage to one part does not affect the others. The arrangement of the body parts in *B. dentata* is consistent, with spines distributed evenly, each being short, blunt, and hard (Luthfi 2021).

Ophiocoma schoenleinii (Müller and Troschel, 1842) (Figure 3.B)

Ophiocoma schoenleinii, or often known as the snake star, is a species of Ophiuroid that has distinctive characteristics that differentiate it from other members. In general, *O. schoenleinii* has a flat, pentagonal body shape (like a pentagonal star) with five long, slender, and flexible arms, which can reach up to 30 cm. The size of the disk can reach up to 2-3 cm in diameter, while the arms can extend up to 10 cm. The arms are covered with small scales that give a rough texture to the surface of the body. Its body color varies, usually consisting of a combination of white, brown, gray, and yellow, which functions as camouflage among the substrate where it lives. The center of the body, or disk, is usually round and has a smaller diameter than the arms, with gaps that facilitate movement. The surface of the body is coarse-grained on top, with small, blunt spines covering the entire body. The species *O. schoenleinii* is also known for its extraordinary regeneration abilities, allowing them to repair limbs lost due to predators or injury. Its natural habitat includes coral reef areas and rocky substrates in tropical waters, where it functions as a detritus feeder, filtering food from passing water. The existence of this species in the ecosystem is very important because it helps maintain the balance of the marine environment (Lesawengan et al. 2019).

Ophiocoma erinaceus (Müller and Troschel, 1842) (Figure 3.C)

This starfish is characterized by a disc with a diameter of about 2-3 cm covered with black grains on the aboral part. In the mouth there are dental papillae and a series of oral papillae. This starfish has five simple arms with cigar-shaped upper arm bones, slender and up to 12 cm long. The species *O. erinaceus* has two tentacle scales on the ventral side. This sea star sample was found to be medium sized and black with brown spots. Its surface is covered with small, sharp spines. The classification of this marine biota is: Kingdom Animalia, Phylum Echinodermata, Class Ophiuroidea, Order Ophiurida, Family Ophiocomidae, Genus *Ophiocoma*, Species *O. erinaceus* (Figure 3.C). The distribution of *O. erinaceus* includes Saipan, Maldives, eastern India, Indian Ocean, Mascarene, Madagascar, Arabia, northern Australia, Philippines, China, southern Japan, southern Pacific, Hawaii, Indo-Pacific Ocean, and Red Sea (Triana et al. 2015).

Ophiocoma scolopendrina (Lamarck, 1816) (Figure 3.D)

Ophiocoma scolopendrina, known as the spotted snake star or scaly snake star, is a member of the class Ophiuroidea. It has five arms up to 15 cm long with short, pointed spines for protection and movement on the rocky seabed. Its body is small, disc-shaped with a diameter of 1-2 cm, and has a striped color pattern for camouflage. This animal is able to regenerate lost arms and has high mobility to find food and avoid danger. As detritivores, they feed on small organic particles in marine sediments. Its habitat is in the intertidal zone to several meters deep, often under rocks or coral reef crevices. Advanced sensory systems allow them to detect environmental changes, making them a successful and widespread species of star snake in tropical and subtropical marine areas (Lestari et al. 2020).

Ophiarachna affinis (Lütken, 1869) (Figure 3.E)

Ophiarachna affinis has a cream-colored base and spines on the arms, which are usually white and gray extending to the ventral spines. The arm length reaches up to 9 cm with a disc diameter of 2.5 cm. The arm pattern is cream and gray with dark stripes, and it is a benthic animal (Sloan et al. 1979). Its habitat is found in shallow waters in coral rubble areas. The distribution ranges in tropical waters, in the Pacific Ocean up to a depth of 25 m, the Red Sea, Eastern Pacific, Eastern India, the Philippines, South Pacific, and Australia (Nurafni et al. 2019).

Ecological index

Diversity index (H')

Diversity index (H') value for each beach location has a low category value (Table 4). Pringjono Beach has a value of 0.63, Torohudan Beach with 0.57, and Dadap Ayam Beach with 0.74. Meanwhile, the three beaches combined had a value of 0.24 (low). The main cause of the low diversity category in all locations is likely due to factors that limit species diversity in these areas. It could be due to environmental disturbances, habitat degradation, or pressures from human activities such as pollution and global warming. Research by Budiman et al. (2014) showed that the number of species or individuals influences the high or low diversity index (H') of species, the presence of abundant species, substrate homogeneity, and the condition of three important ecosystems in coastal areas such as seagrass beds, coral reefs, and mangrove forests as habitat for aquatic biota. In addition, research by Jiao et al. (2019) also showed that the diversity index (H') has a high value if all individuals come from different genera or species, while the lowest value occurs if all individuals come from one genus or species with an even distribution. Therefore, irregularity in the distribution of individuals can lead to low diversity.

Evenness index (E)

The evenness index (E) values for Pringjono Beach, Torohudan Beach, and Dadap Ayam Beach are 0.46, 0.43, and 0.41, respectively, with all three in the low category (Table 5). If calculated in total from the 3 beaches, it also produces a value that is included in the low category, namely 0.15. Research conducted by Soliha and Rahayu (2018) shows that the uneven distribution of individuals of each species causes the low evenness index in habitats. It is because there is only one species that lives very abundantly in the number of individuals on the three beaches; the most dominating is *O. dentata*. If the species found in a community have an unequal number of individuals of each species, then the evenness in the community is low. The unevenness of the Ophiuroidea species is thought to be caused by the distribution of the number of individuals of each species not spreading evenly or caused by physical-chemical environmental factors (Kambey et al. 2015).

Another factor that supports *B. dentata* species as the most commonly found species compared to other species is the ecological and habitat conditions that support the needs of this species (Pakpahan et al. 2020). *Breviturma dentata* is a brittlestar species that is usually found in areas with hard substrates, such as boulders, bedrock, and gravel, in areas exposed to water with some water movement (Kaharudin et al. 2023). This species was also found in moderate areas exposed to water with some water movement. This condition is in accordance with the needs of this species, which requires a hard substrate to live and is exposed to water with some water movement. The beaches used as research sites also have substrate characteristics in the form of sand and dead coral beds that are overgrown with macroalgae (Komala et al. 2024).

Richness index (R)

Richness index (R) value for each beach location has a medium category value, namely: Pringjono Beach with a value of 0.52; Torohudan Beach with a value of 0.55, and Dadap Ayam Beach has a richness index (R) value of 0.66 (Table 6). The total of three beaches have a richness index (R) value of 0.62, which is also included in the medium category. Research conducted by Dharma et al. (2019) showed that the moderate Richness Index in marine animals was due to several factors. First, the richness index (R) is influenced by the value of diversity, which in some studies, as in this study, is in the medium category. Second, the richness index is also influenced by the dominance value. However, if the dominant species at each point is a relatively rare species, then the richness index can be in the moderate category. In addition, the richness index is also influenced by the distribution pattern of the species. If the distribution pattern is not too homogeneous, then the richness index can be in the medium category. In general, species richness in a community is strongly influenced by various interrelated factors, especially by environmental quality, both physically and chemically (Binambuni et al. 2019).

As well as research conducted by Jalaluddin and Ardeslan (2017) found that Ophiuroidea consists of one species with 76 individuals. The species found was *O. erinaceus*, and the research was conducted in the coastal waters of Sembilan Village, West Simeulue Sub-district, Simeulue District, Indonesia. This area is known to have a variety of habitats, such as coral reefs, rocks, and sand. In addition, in research conducted by Lestari et al. (2020) in Seupang Beach, Lebak District, Banten, Indonesia, two species of Ophiuroidea were found, namely *O. scolopendrina* and *O. nigra*, with the number of individuals totaling 803 and 216, respectively. In the last study conducted by Turner et al. (2021), the research and sampling locations were at Tebing Beach, Indonesia, where two species were found, namely *O. erinaceus* and *O. scolopendrina*, with the number of individuals being six and one, respectively. When compared to the research at Pringjono Beach, Torohudan Beach, and Dadap Ayam Beach, five species of Ophiuroidea were found, including *O. dentata, O. affinis, O. schoenleinii, O. erinaceus,* and *O. scolopendrina*, with a total number of individuals of 495, 21, 71, 7, and 55, respectively, spread across the three Gunungkidul beaches. These findings indicate significant species diversity in the region, which may expand the understanding of the geographical distribution and abundance of these species and try to understand the environmental factors that influence the presence of the five species.

Environmental factors

The study was conducted at three beaches that had several abiotic environmental parameters measured. The physicochemical parameters of the waters have a major impact on the presence of species in the ecosystem. From the data listed in Table 7, the results of temperature measurements at the three beaches show that Pringjono Beach has a temperature of 27-30.8°C, Torohudan Beach has a temperature of 28-30.3°C, and Dadap Ayam Beach has a temperature of 28-30.1°C. This finding is in line with research by Olsen et al. (2015), which states that the optimal water temperature for Ophiuroidea life ranges from 25 to 30°C. Based on temperature parameters, the three beaches are still suitable as habitats for Ophiuroidea despite being in extreme environmental conditions, with the highest tolerance limit reaching 35°C. If the water temperature exceeds 35°C, marine animals are likely to experience stress.

Other environmental factors that affect Ophiuroidea growth, such as water pH, were also measured in this study (Malik et al. 2023). Water pH is important to measure because it affects many aspects of aquatic ecosystems, including the health and growth of organisms. In addition, water pH can affect the solubility and availability of nutrients as well as the toxicity of dangerous chemicals (Alengebawy et al. 2021). The pH measurement results showed that Pringjono Beach had a pH of 6.98-7.92, Torohudan Beach had a pH of 8.26-8.55, and Dadap Ayam Beach had a pH of 8.26-8.38. According to Sahetapy et al. (2014), Ophiuroidea can live in seawater with a pH range between 7 and 8.5. Therefore, the pH in the three beaches is considered normal for Ophiuroidea growth. In addition, Dissolved Oxygen (DO) levels were measured. Pringjono Beach has a DO of 0.70-2.31, Torohudan Beach has a DO of 0.30-0.49, and Dadap Ayam Beach has a DO of 0.49-1.70. Based on Sutisna's research (2018), Ophiuroidea requires a minimum DO level of around 4 to 6 mg/L to maintain health and survival. The measurement results show that DO conditions on the three beaches are far below the threshold required for Ophiuroidea life, which is likely to be a contributing factor to the limited number of species in this study.

In conclusion, this study identified five species of Ophiuroidea from two families, Ophiocomidae and Ophiomyxidae. The five species found were *B. dentata*, *O. affinis*, *O. schoenleinii*, *O. erinaceus*, and *O. scolopendrina*. The species *B. dentata* was observed to be the most dominant species, with 495 individuals per 1,000 m^2. Pringjono Beach had the highest density, followed by Torohudan Beach and Dadap Ayam Beach. Ophiuroidea in the three beaches had diversity index (H') and evenness index (E), which were classified as low, while the richness index (R) was classified as moderate. Environmental factors such as water temperature, water pH, and DO may affect species density in these areas. In the future, it is important to continuously monitor and understand the complex interactions between organisms and their environment for the preservation of a balanced coastal ecosystem.

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