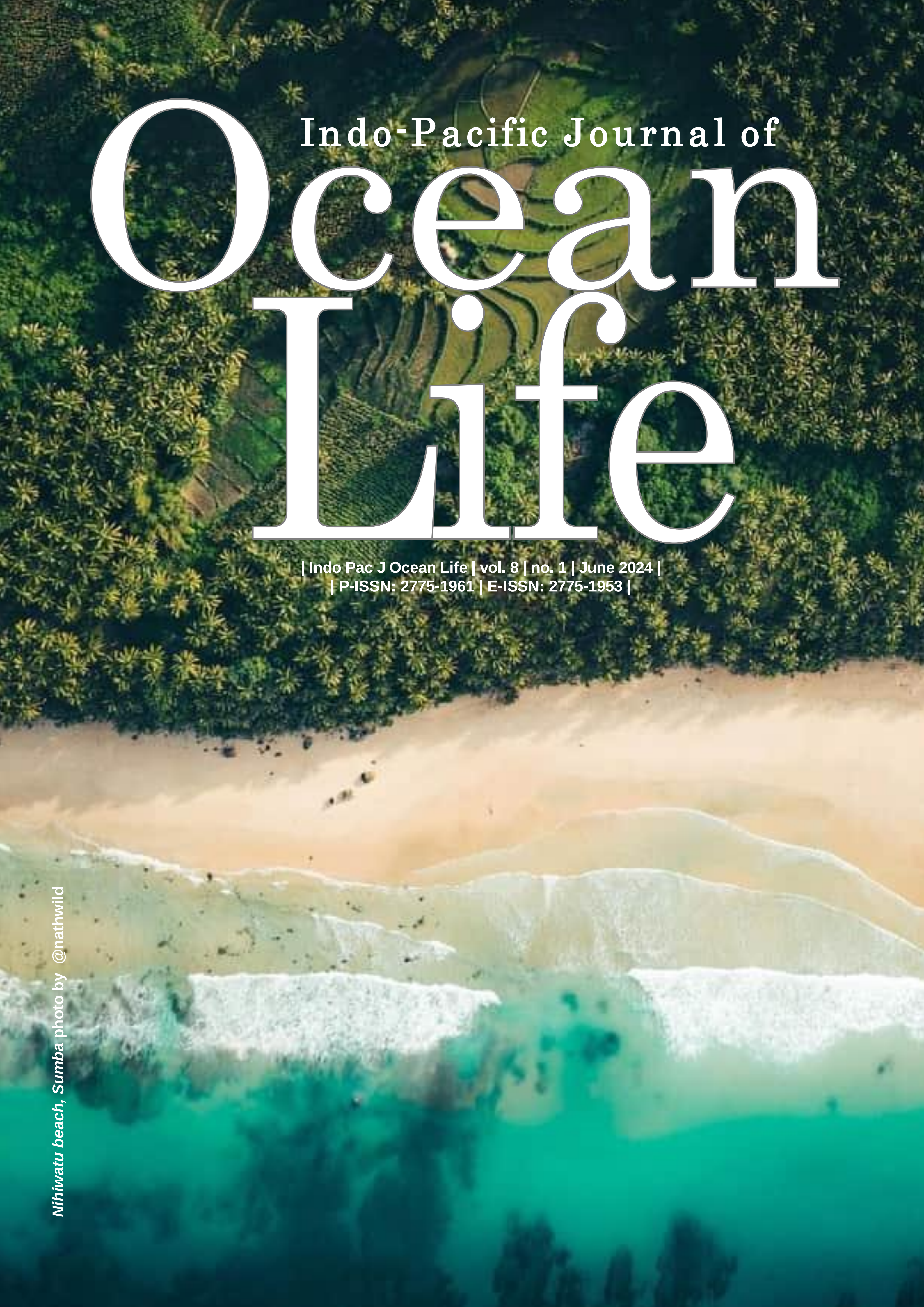

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Abstract A concise abstract is required (about 200 words). The abstract should be informative and state briefly the aim of the research, the principal results and major conclusions. An abstract is often presented separately from the article, thus it 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.

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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.

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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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Enabling conditions for the rehabilitation and preservation of mangrove ecosystem in Sampang, Madura Island, Indonesia

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[3]Department of Aquaculture, Faculty of Fisheries and Marine Science, UniversitasJenderal Soedirman. Jl. Dr.Soeparno, Purwokerto Utara,Banyumas 53122, Central Java, Indonesia

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Abstract. *Aftsari I, Pramono CL, Alyodya DA, Nurwulandari M, Sujarta P, Dadiono MS, Yap CK, Setyawan AD. 2024. Enabling conditions for the rehabilitation and preservation of mangrove ecosystem in Sampang, Madura Island, Indonesia. Indo Pac J Ocean Life 8: 1-9.* Mangroves are a very productive ecosystem that is important to the environment and human welfare. Rehabilitation activities need to be carried out to restore mangrove forests that have experienced degradation. In doing so, local communities have an important role because their involvement can minimize human disturbance and realize sustainable mangrove management. This research aims to determine the circumstances that can facilitate or prohibit local communities in the rehabilitation of mangrove forests in Sampang District, Madura Island, East Java Province, Indonesia. This research was conducted in two villages in Sampang District, i.e.: Taddan and Gulbung in December 2023 using two methods, namely remote sensing analysis to determine changes in mangrove cover from 2008 to 2023 and in-depth interviews to determine the role and strategies of the community in mangrove rehabilitation. The remote sensing analysis shows significant increase in mangroves in Taddan Village from 54.7757 ha in 2008 to 101.718 ha in 2023 (+46.9422 ha). During the same period, mangroves in Gulbung Village increased from 21.6928 ha to 30.6723 ha (+8.9795 ha), although there was a decreasing trend during the period of 2013-2023. There is a difference in situation between the two villages, where in Taddan there are rehabilitation and conservation activities, increasing mangroves, while in Gulbung some mangroves have been converted into salt ponds, especially during the last decade. The results of the interviews revealed that public knowledge and awareness regarding the benefits and importance of mangrove management are still low. We also found that the facilitation from governments and the formation of community groups might enable the preservation and rehabilitation of mangrove forests.

Keywords: Mangrove, rehabilitation, remote sensing

INTRODUCTION

Mangroves are a very productive ecosystem found in tidal zones in tropical and subtropical regions. Mangroves play an important function in protecting coastlines from abrasion and flooding, as well as protecting buildings and crops from damage caused by storms containing salt water (Gumay 2022). In addition, it reduces storm surge water levels by slowing water flow and reducing strong waves and wind (Deb and Ferreira 2017). Mangroves are also essential in mitigating climate change by absorbing carbon three to five times higher than carbon storage in terrestrial forests (Eddy et al. 2021). Takarendehang et al. (2018) state that mangrove ecosystem has important ecological and socio-economic roles. From an ecological perspective, mangroves serve as habitat for various marine biotas and play an important role in maintaining the food chain (Singh 2020). From an economic perspective, mangroves provide various resources for local communities, from fisheries to timber for charcoal or building materials (Safe'i 2022). More recently, mangrove ecosystems have increasingly developed to play role in the social aspect, namely as a place for tourism, recreation and education (Quinn et al. 2017).

Mangroves can respond to climate change, geological, chemical, biological and physical phenomena with spatial and temporal patterns (Mandal and Bar 2018). They have specialized morphological adaptations for survival and have special mechanisms for salt tolerance (Sudhir et al. 2022). Mangrove forests consist of vegetation communities, ranging from mixed to pure stands. Mangrove communities worldwide are dominated by four genera, namely *Sonneratia*, *Rhizophora*, *Bruguiera*, and *Avicennia* (Veettil et al. 2019).

Malaysia and Indonesia are countries in Asia with the largest mangrove areas (Romañach et al. 2018). Indonesia alone has the largest mangrove forests in the world, with a total area of 3.31 million ha (Arifanti 2020). In Indonesia, mangrove forests are spread across five large islands: Java, Kalimantan, Sulawesi, Papua, and Sumatra (Kusmana 2014). Basyuni et al. (2022) state that most mangrove forests are spread across eastern part of Indonesia. Despite the large extent and high importance, mangrove forests in Indonesia have been degraded and converted into other land uses in the last few decades. According to the Ministry of Forestry and Environment, 430,000 ha mangrove forests have been degraded in the period 1985 to 2019.

Mangrove forests have been heavily impacted by degradation and deforestation (Goldberg et al. 2020). This is due to forest clearing for fish pond development and exploitation for producing wood and raw materials, as well as rapid coastal population growth and urban expansion (Thomas et al. 2017). Therefore, mangrove rehabilitation is promoted to reverse mangrove loss and degradation. In Indonesia, community-based mangrove management and rehabilitation are considered successful in providing benefits for ecology, economy, socio-cultural, and institutional sustainability (Damastuti and Groot 2017). However, several problems remain, including the high death rate of planted mangrove seedlings especially when the planting is carried out in permanently flooded areas (Hilmi et al. 2022).

Madura Island is among the islands in Indonesia with the presence of mangroves. The area of mangrove forests in Madura Island is 15,118.2 ha (Muhsoni 2014). However, over 10 years, there has been continuous degradation of the mangrove area in Madura, for example, 276.38 ha of mangroves in Sampang District are degraded due to land conversion and coastal reclamation (Hidayah et al. 2015). According to Hidayah and Rosyadi (2019), high mangrove degradation in Madura Island makes it necessary to rehabilitate mangrove forests. This rehabilitation activity can positively impact the economic development of communities around the coastal area (Wahyurini and Harisudin 2021). Local communities have an important role in mangrove management because their involvement can minimize human disturbance and realize sustainable use of mangrove resources (Martuti et al. 2018). So, further research is necessary to determine the level of community participation in conserving and rehabilitating mangrove forests to manage sustainably.

This research aims to determine the situation and conditions faced by the coastal communities in Sampang, Madura Island which leads to the rehabilitation and preservation of mangrove forests on the coast of Sampang.

MATERIALS AND METHODS

Study area and period

This research was conducted in Taddan Village, Pangarengan Sub-district and Gulbung Village, Camplong Sub-district of Sampang District, Madura Island, East Java Province, Indonesia (Figure 1), in December 2023. The research was conducted in two villages, namely Gulbung and Taddan villages. Data collection was carried out in the mangrove area along the coast of the two villages and adjusted to field conditions based on accessibility (Figure 2). The area of mangroves in Sampang District is 362.177 ha, covering Sreseh, Pangarengan, Sampang, and Camplong Sub-districts (Tsani and Muhsoni 2022) with mangrove extent in Camplong reaching 48 ha (Pratiwi and Muhsoni 2021).

Data collection procedures

The data used in this research were primary and secondary data obtained through two methods: in-depth interviews and remote sensing. Remote sensing was used to determine the changes in mangrove areas from 2008 to 2023. Primary data was collected through semi-structured questionnaires regarding community knowledge and contributions to mangrove preservation and rehabilitation and in-depth interviews with respondents determined using a purposive sampling method with one key informant in *Tagana* (*Taruna Siaga Bencana* or Disaster Preparedness Youth Group) of Taddan Village and 60 respondents (30 people for each village); there were no special criteria for the respondents selected, and all people had the same opportunity to become respondents. The interview aimed to obtain community knowledge about the importance of sustainable mangrove forest management. Besides the interviews, field observations were carried out to obtain supporting data on the actual condition of mangrove forests on the coast of Sampang, Madura Island.

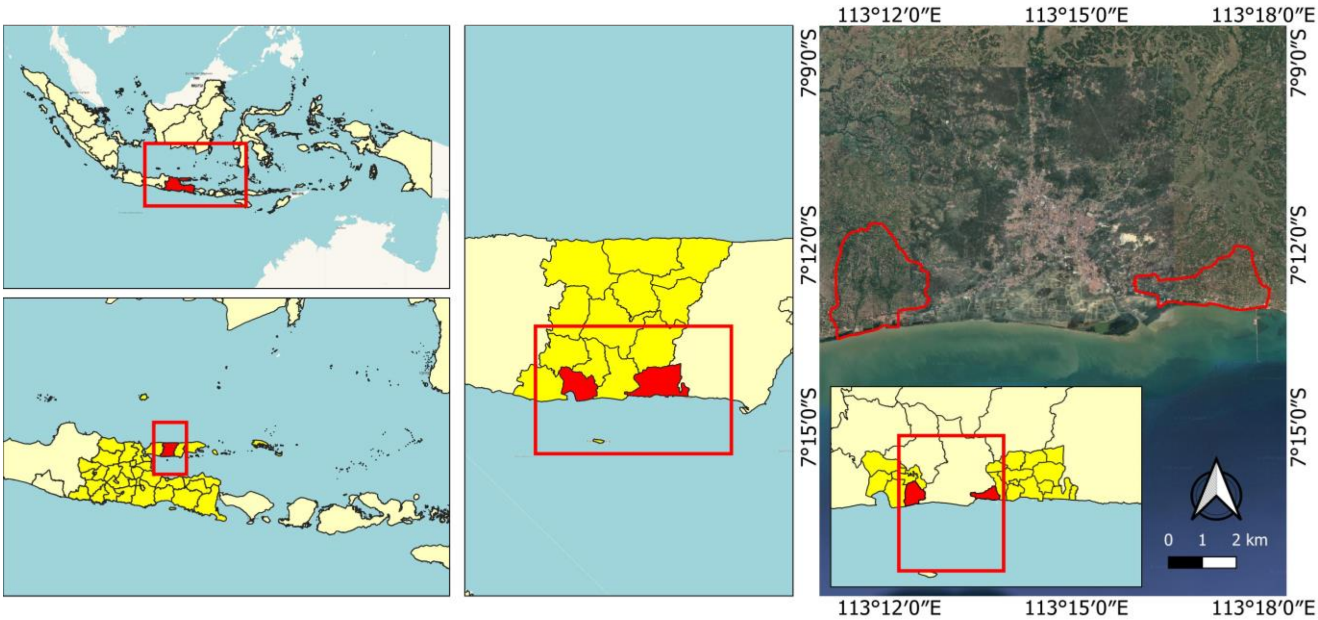

Figure 1. Map of research locations in Taddan and Gulbung villages, Sampang District, East Java Province, Indonesia

Figure 2. The condition of mangrove ecosystem in A. Taddan Village, Pangarengan Sub-district and B. Gulbung Village, Camplong Sub-district of Sampang District, East Java Province, Indonesia

Meanwhile, secondary data was obtained from remote sensing and literature studies relevant to the topic discussed. This study used Landsat 7 and 8 satellite images in the last 15 years (2008 to 2023). This time range was chosen to map the distribution of mangrove density every 5 years, namely in 2008, 2013, 2018, and 2023. Landsat 7 satellite images were used in 2008, while Landsat 8 satellite images were used in 2013, 2018, and 2023. The Landsat image used is Landsat Collection 2 Level 1 on the coast of Taddan and Gulbung villages. Landsat 7 and 8 satellite images were freely downloaded from https://www.earthexplorer.usgs.gov/. Satellite imagery is used to evaluate mangrove land changes over 15 periods.

Data analysis

NDVI calculation

The NDVI (Normalized Difference Vegetation Index) is used to analyze the changes in vegetation cover (Hashim et al. 2019). The NDVI is often used to determine the state of vegetation in an area because it can capture the density of green vegetation at a spatial resolution of 30 meters (Bid 2016). The NDVI was calculated as follows (Barbosa et al. 2006):

$$NDVI = \frac{NIR - Red}{NIR + Red} \quad [1]$$

Where:
NDVI : Normalized Different Vegetation Index
NIR : Near Infrared

NDVI ranges from -1 to 1, and non-vegetation objects such as clouds, water, and other objects have values less than zero. Meanwhile, objects representing vegetation have a value range of 0.1 to 0.7. The NDVI range for mangrove forest density has a value range of 0.1-0.6. The higher the value, the healthier the vegetation cover (Hardianto et al. 2021).

In-depth interviews and questionnaire

The results of in-depth interviews and literature studies data were analyzed descriptively through historical explanations. Then, such results were compared with the remote sensing data analyzed using the NDVI method to compare mangrove cover changes between 2008, 2013, 2018, and 2023.

RESULTS AND DISCUSSION

The extent and dynamics of mangrove forests in coastal areas in Sampang District

The result of remote sensing analysis shows that the area of mangrove forests in Taddan Village is quite high with 101.718 ha in 2023 (Table 1). Every year, the area of mangrove forests in Taddan Village increased significantly. Table 1 and Figure 3 shows that between 2008-2013, the area of mangrove forests in this village increased by 15.0762 ha, from 54.7757 ha to 69.8519 ha. Furthermore, in 2013-2018, there was an increase of 31.7121 ha, from only 69.8519 ha to 101.564 ha. Meanwhile, in 2018-2023, there was an increase of 0.1540 ha, from 101.564 ha to 101.718 ha. The total increase in mangrove forest area from 2008 to 2023 is 46.942 ha.

Based on the results of interviews, the increase in the area of mangrove forests in Taddan Village was due to several factors, including the rehabilitation program by planting mangrove seedlings arranged by the Ministry of Marine and Fisheries and the formation of a mangrove rehabilitation group. Apart from that, another factor is that village communities were also invited to clean the mangrove forest and plant mangrove seedlings. The increasing mangrove forest in Taddan Village positively impacts the community by minimizing abrasion and increasing the village economy because the mangrove forest in this village is used as an educational tourism site (Purwanti et al. 2020).

Meanwhile, in Gulbung Village, the area of mangrove forest in 2023 is only 30.6723 ha (Table 1, Figure 4). Between 2008 and 20123, the mangrove forest in this village experienced decrease and increase. Table 1 revealed that in the 2008-2013 period, there was an increase of 16.6217 ha, from 21.6928 ha to 38.3146 ha. However, from 2013 to 2018, the area of mangrove forests decreased by 6.8285 ha, which became 31.4860 ha. Then, during 2018-2023, the area of mangrove forests in this village decreased by 0.8137 ha, resulted in 30.6723 ha of mangrove forest in 2023. In summary, from 2008 to 2023, the area of mangrove forests increased by 8.9795 ha, but there is a decreasing trend toward nowadays. This loss of mangroves is because of the expansion of salt ponds in this village. Other influencing factors are the absence of conservation groups, followed by the lower public's understanding of the ecological importance of mangrove forests. If it continues unabated, this condition will increase the risk of abrasion and land subsidence in Gulbung Village (Alfandi et al. 2019).

Table 1. The extent and changes of mangrove forests along the coast of Taddan and Gulbung villages, Sampang District, East Java Province, Indonesia

Year	Extent of mangrove forest (ha)		Changes of mangrove forest (%)	
	Taddan	Gulbung	Taddan	Gulbung
2008	54.7757	21.6928	-	-
2013	69.8519	38.3146	+15.0762	+16.6217
2018	101.5640	31.4860	+31.7121	-6.8285
2023	101.7180	30.6723	+0.1540	-0.8137
2008-2023			+46.9422	+8.9795

Note: positive means increase in extent; negative means decrease in extent

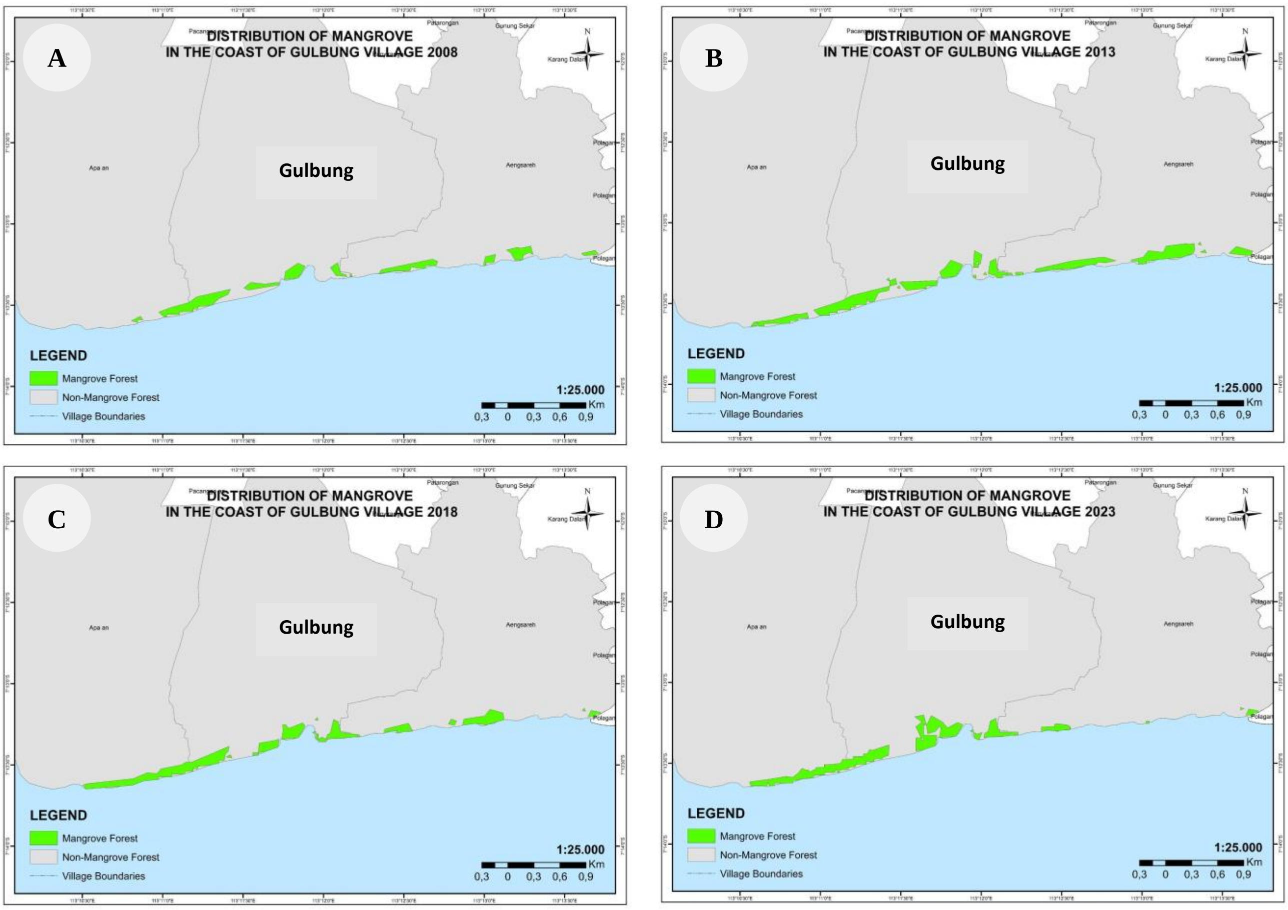

Figure 3. Spatial distribution of mangrove forests along the coast of Gulbung Village, Sampang District, East Java Province, Indonesia in: A. 2008, B. 2013, C. 2018, D. 2023

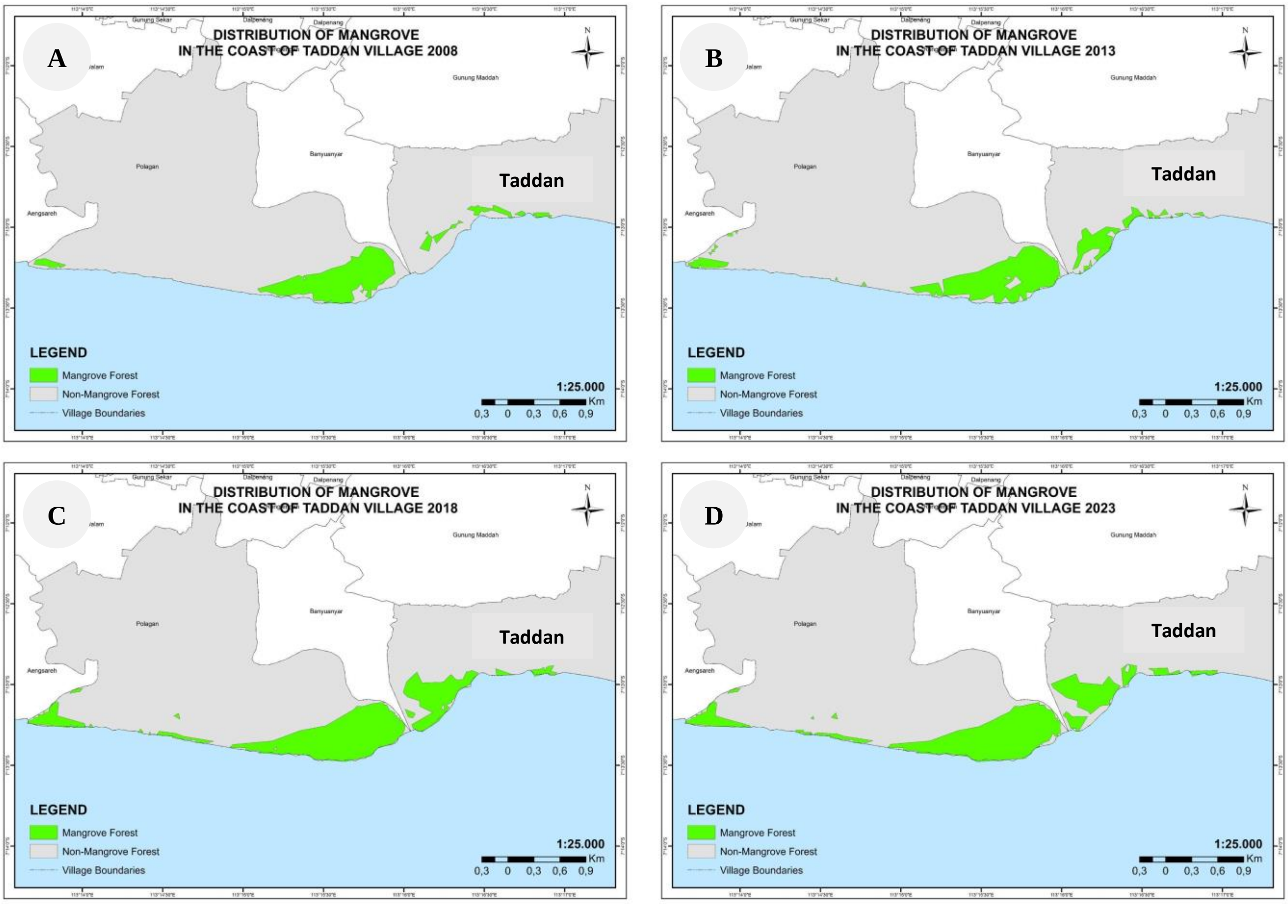

Figure 4. Spatial distribution of mangrove forests along the coast of Taddan Village, Sampang District, East Java Province, Indonesia in: A. 2008, B. 2013, C. 2018, D. 2023

The difference in result between the two villages is related to several factors, but mainly due to the presence of salt ponds. Salt ponds in Gulbung Village have essential socio-economic roles (Bachri et al. 2020) where the many salt ponds in this village improve the economy of the surrounding community so that Madura Island is known as a salt-producing island (Widyanti and Setiyonugroho, 2022). However, the uncontrolled growth of salt ponds has disrupted the mangrove ecosystem, affecting biodiversity and communities (Siddig et al. 2020). The other factor was the very low public understanding of the importance of mangrove forests (Dharmawan et al. 2016). The low knowledge of the importance of mangroves led to their degradation since they could not manage them (Cahyaningsih et al. 2022).

Community's knowledge regarding the benefits of mangrove forests

The result of interviews shows that some people are aware of the existence of mangrove forests on the coast of Sampang, Madura Island. However, public knowledge regarding the benefits of mangrove forests, both in terms of ecological and economic aspects, is still limited. The interviews with coastal communities in Sampang, Madura Island, revealed a low understanding, especially regarding the benefits of mangrove forests as a place for animals to grow and breed and the benefits to their economy. Most people do not know about these benefits. Around 72.1% of people do not know the benefits of mangroves as an animal habitat, and 65.6% do not know the benefits of mangrove forests for the community's economy (Table 2). This is particularly eminent among the people in Gulbung Village, whose knowledge about the benefits of mangrove forests is lower than those in Taddan Village, resulting in the people not preserving the existence of mangrove forests because they do not know the importance and many benefits of mangrove forests (Nanlohy and Masniar 2020).

There are differences between the mangrove forests in Gulbung and Taddan villages. The mangrove forest in Gulbung Village has experienced degradation due to its conversion to salt ponds. The managers consider salt ponds more profitable than preserving mangroves, so the mangrove forest is converted into salt ponds to increase economic benefits (Friess et al. 2020). The remaining mangrove forests are only to protect the salt ponds from being affected by abrasions. Furthermore, this coastal community does not deeply understand the benefits of mangrove forests, such as a habitat for various animals, protection from tsunamis, benefits for the economy, and others (Indarsih and Masruri 2019). Meanwhile, in Taddan

Village, the community said they usually use mangroves as animal feed, firewood, cigarette paper, and fishing in the mangrove ecosystem. According to Sri et al. (2023), mangrove leaves can be used in making cigarette paper. Therefore, the interviews show that the knowledge of coastal communities in Taddan Village regarding the benefits of mangroves is higher than that of communities in Gulbung Village. Overall, the awareness among the coastal communities in Sampang, Madura Island regarding the importance of mangrove forests for the balance of the coastal environment and the various benefits of mangroves for life is still relatively low.

Table 2 shows that most people know the benefits of mangroves as protection against tsunamis, preventing water intrusion, and protecting settlements from abrasion and sea winds. However, the community does not understand the benefits of mangroves as animal habitats and supporting their economy. So that people know more about the ecological benefits than the economic benefits of mangrove forests for their living. This result differs from the research conducted by Iswandaru and Febryano (2021), who found that people tend to know that mangroves can be used to generate livelihoods including the harvesting of crabs, shrimp, and leaves or fruit that can be used as medicine.

The roles of coastal community in mangroves rehabilitation

According to Amal and Baharuddin (2016), the community's role in mangrove rehabilitation is their involvement, starting from thinking, planning, implementing, monitoring, and evaluating. The participation of the coastal community in Sampang, Madura Island in mangrove rehabilitation is relatively low because community's knowledge about the importance of mangroves is also still low. This is supported by interview results, which show that 85.2% of the community did not participate in mangrove forest rehabilitation (Table 3). In Taddan Village, several efforts to preserve and rehabilitate mangrove forests are mostly conducted by a special group called *Pokmaswas Permata* (Permata Supervisory Community Group). Based on information from *Tagana* as a key informant interview, *Pokmaswas Permata* was formed in 2019, starting with the awareness of Sampang youth on the importance of mangrove forests for the sustainability of Madura's coastal areas. Apart from *Pokmaswas Permata*, *Tagana* Sampang also plays a role in rehabilitating mangrove forests on the coast of Sampang, Madura Island.

The mangrove rehabilitation program was carried out in 2020 with the planting of 130,000 seedlings arranged by the Ministry of Marine and Fisheries (*Kementerian Kelautan dan Perikanan*/KKP 2020). The background that drove this rehabilitation activity was the awareness of mangroves' extraordinary benefits and potential. Moreover, the degradation of mangrove forests reduces the mangrove ecosystem's biota and affects some road networks. Therefore, some people know the importance of rehabilitation, starting a movement to conserve mangroves and maintain their survival. Then, they proposed the local Marine and Fishery Services (*Dinas Kelautan dan Perikanan*/DKP) to form a mangrove rehabilitation and conservation group, namely *Pokmaswas Permata*. Next, the DKP continued the proposal to the KKP. Finally, the KKP provided 130,000 mangrove seedlings, and *Pokmaswas Permata* was formed in 2019 and then they carried out a rehabilitation program. The mangroves planted were *Rhizophora stylosa*, *Sonneratia alba*, and *Avicennia marina*.

Before the rehabilitation program, mangrove forest conservation activities conducted by the community were only in the form of cleaning and establishing nursery in 2017. However, after being established in 2019, the nursery activities were still only carried out by the *Pokmaswas Permata* group and did not involve community participation. So, the coastal communities in the studied area have not been fully involved in mangrove forest rehabilitation, and most of the rehabilitation activities were carried out by *Pokmaswas Permata*. Therefore, the limitations to managing mangrove forests on the coast of Sampang, Madura Island, were the lack of land permits and low public awareness. Also, barnacle disease which attacked mangroves hindered mangrove growth. Risnasari et al. (2021) state barnacles (subclass Cirripedia; subphylum Crustacea) are invertebrates attached to wood or other hard objects in sea and brackish waters. Barnacles are a type of pest which attacks seedlings to sapling levels in mangroves that generally stick to the stems, and their presence is a serious problem because it inhibits growth and damages mangroves (Haneda and Suheri 2018). The barnacle pests can be eradicated by spraying with crustacean repellent (Mustafirin 2016). To increase public awareness, it is necessary to carry out more regular campaigns regarding the benefits and importance of mangrove forest conservation efforts and make written regulations prohibiting all things that can damage mangrove forests. Based on the interviews in Gulbung Village, the local community does not manage the mangrove forest. Mangrove forests are only managed by the government and salt pond owners to protect their ponds; the community does not know more about the activities carried out to rehabilitate mangroves in that they are not directly involved.

Table 2. The knowledge of communities in Taddan and Gulbung villages, Sampang District, Indonesia regarding the benefits of mangrove forests

Aspect	Yes (%)	No (%)
Mangrove forests are a place for animals to grow and breed (shrimp, crabs, squid, etc.)	27.9	72.1
Mangrove forests function and importance for protecting coastal area against tsunami disasters	72.1	27.9
Mangrove forests function and importance for preventing water intrusion	59.0	37.7
Mangrove forests function for protecting settlements from abrasion and sea winds	62.3	36.1
Mangrove forests are useful to the community's economy	34.4	65.6

Table 3. Results of interviews regarding community participation in mangroves rehabilitation

Question	Yes (%)	No (%)
Are you aware of any mangrove rehabilitation activities?	50.8	49.2
Do you participate in mangrove rehabilitation activities?	13.1	85.2

Strategies of coastal community to maintain the existence of mangroves

Strategies to maintain the existence of mangroves are very necessary (Hillary et al. 2019), and one solution that can be done is through conservation. However, the mangrove forests in Taddan and Gulbung villages do not yet have conservation permits. Thus, providing regulations for the community is a little bit hampered. There should be also cooperation between the government, conservation managers, and the community (Mahifa et al. 2018). Based on the results of interviews with *Tagana* as a key informant, socialization has been carried out regarding the function of mangrove forests as of 2021. Many people are aware of the mangrove forest rehabilitation movement in *Pokmaswas Permata*, but only a few people are participating in this activity. This is because people's understanding of the function of mangroves is still very low; thus many people still illegally cut down mangroves, which are used for animal feed, firewood, building materials, and much more.

Mangrove forest management strategies include the implementation of government policies to maintain the potential of mangrove ecosystem resources, utilization of the potential of mangroves as ecotourism and educational activities, revitalization of traditional institutions as an effort to manage mangrove forest areas, and increase knowledge and awareness of local communities regarding the function of mangrove forests. For example, in Taddan Village, the strategy that can be implemented is collaboration between the community and the government. By granting a conservation land permit, the management of mangrove forests at the village level will lead to better and greater community involvement in conservation. The community is expected to participate in managing mangrove forests directly or indirectly, such as through outreach activities to clean the coast. Meanwhile, in Gulbung Village, an effort must be conducted to reach the entire community to increase public awareness of the importance of mangrove forests for their lives.

Important lessons from sustainable mangrove management in Sampang

The success story of sustainable mangrove management in Taddan Village started with reforestation and conservation. Activities conducted successfully minimize abrasion, maintain seawater levels to become not too salty, and apply the mangrove area as an educational tourism site. Community has an important role in managing natural resources to maintain the existence of mangrove forests on the coast of Sampang, Madura Island (Hidayah et al. 2020). Some people already understand that mangrove forests must be preserved and cannot be cut down haphazardly. The community has also started to participate in the movements organized by *Pokmaswas Permata*, such as counseling, community service, cleaning mangrove forests, and much more. Furthermore, many actions have been taken to support mangrove conservation, including routine beach clean-ups, collaboration with organizations and communities for mangrove planting activities, collaboration with state-owned companies (BUMN) to obtain CSR (Corporate Social Responsibility), and conducting training to process mangrove byproducts. Based on the results of interviews with *Tagana* as a key informant, sustainable mangrove management in the studied area occurs through a bottom-up scenario, which the village youth promoted during the initial stage. The early stages initiated by the village's youth improved their knowledge, skills, and social attitudes toward preserving and managing the mangrove area so that it can be properly managed and used wisely (Hur et al. 2021).

Based on the research results, the area of mangrove forests in Taddan and Gulbung villages, Sampang District, Madura Island, experienced changes between 2008 and 2023 with dynamics of both increasing and decreasing. The most significant increase was in Taddan Village, which previously was only 54.7757 ha in 2008 but is now 101.718 ha. During the same period, the area of mangrove forest in Gulbung Village was only 21.6928 ha and increased to 30.6723 ha, although there was a decreasing trend from 2013 to 2023. There are distinct differences between the two research locations, namely that mangroves in Taddan Village increased due to the rehabilitation movement. Conversely in Gulbung Village, the decrease of mangroves was due to the conversion of mangroves into salt ponds. Some people in the coastal area in Sampang, Madura Island still do not understand mangroves' function and important role in their lives. The results of interviews show that community knowledge regarding the benefits of mangrove forests is still relatively low. The rehabilitation movement that was carried out in 2020 involved planting of 130.000 seedlings. However, in the rehabilitation movement, the involvement of the community is still limited and relatively low. Therefore, further efforts are important to increase public understanding and awareness of preserving and rehabilitating mangrove forests. Many efforts to rehabilitate mangrove forests can be carried out by implementing government policies to maintain the potential of mangrove ecosystem resources, utilizing the potential of mangroves as ecotourism and educational activities, revitalizing traditional institutions as an effort to manage mangrove forest areas, and increasing knowledge and awareness of local communities regarding the function of mangrove forests.

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Diversity of waterbirds around Ekasoghi mangrove area, Sumenep, with the first record of Australian tern (*Gelochelidon macrotarsa*) from Madura Island, Indonesia

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Manuscript received: 30 January 2024. Revision accepted: 4 March 2024.

Abstract. *Andrimida A, Sonhaji A, Hardiyan FZ. 2024. Diversity of waterbirds around Ekasoghi mangrove area, Sumenep, with the first record of Australian tern (*Gelochelidon macrotarsa*) from Madura Island, Indonesia. Indo Pac J Ocean Life 8: 10-17.* Mangrove forests provide an essential habitat for a lot of organisms, and they also provide an important habitat for waterbirds. This study aims to provide an overview of waterbirds' diversity and abundance around Ekasoghi mangrove area situated on the eastern coast of Sumenep, Madura Island on East Java, Indonesia. This research was conducted at three stations, each representing a different habitat type around Ekasoghi mangrove area. Waterbird data was collected using the exploration method, and waterbird species were determined by examining their morphological characteristics. Waterbirds' diversity was determined using the Shannon-Wiener diversity index, and the abundance was determined using the abundance index. Moreover, 38 individuals belonging to 15 species from 4 orders and 6 families were recorded during this study, with more than half belonging to the Charadriiformes order; the waterbird diversity index ranged from the highest 1.97 to the lowest 1.33. Three species with the highest abundance index value are striated heron (*Butorides striata*) with an abundance index value of 18.42, followed by Javan plover (*Anarhynchus javanicus*) and common sandpiper (*Actitis hypoleucos*) as the second with an abundance index value of 13.16. This research also provides the first record of the migrating seabird Australian tern (*Gelochelidon macrotarsa*) from Madura Island.

Keywords: Charadriiformes, distribution extension, new record, waterbirds

INTRODUCTION

Mangrove forests hold an enormous amount of biodiversity within their ecosystem; various animals from different taxa, from fishes to mammals, reptiles, and waterbirds, are known to inhabit the ecosystem of mangrove forests (Kaskoyo et al. 2023). It provides sheltering, foraging, breeding, and hiding sites and a place to perch, especially for waterbird families (Nurrofik et al. 2021). It also provides a habitat for several types of marine organisms, like fish and invertebrates, to breed, further providing an important food source for waterbirds (Salahuddin et al. 2021). The structural integrity of the mangrove trees also provides a potential nesting site, especially for large waterbird species (Mardiastuti et al. 2023). In addition, the mangrove ecosystem provides physical coastal protection from wind and abrasion, as well as sequestering carbon and remediates pollutants (Salahuddin et al. 2021; Ramadhani et al. 2022)

Waterbirds are a group of birds that are ecologically dependent on the existence of wetlands (Dilrangi et al. 2021), which include different types of habitats such as mangroves, marshes, mudflats, lakes, aquaculture ponds, and rice paddies (Makkatenni et al. 2023). Waterbirds is a large group of birds that includes species from the Anseriformes, Charadriiformes, Ciconiiformes, Gaviiformes, Gruiformes, Pelecaniformes, Podicipediformes and Procellariformes orders (Manikannan et al. 2012). The recent Ramsar Convention also proposes to include some species of raptors and passerines in the waterbirds category (Marigmen 2023). The diversity of waterbirds, with their distinct characteristics and behaviors, has made them occupy many essential roles within the mangrove ecosystem. These roles include predators, seed vectors, providing habitat for invertebrate populations, and maintaining the nutrient cycle within mangrove areas (Arzel et al. 2015). Some waterbirds that feed by probing the soil with their bills help oxygenate it and provide nutrients to the surrounding waters by releasing their feces and food left over (Purify et al. 2019).

Birds are among organisms that are very sensitive to environmental changes, which means birds could be used as an appropriate indicator in monitoring changes within an ecosystem (Rachmaputra et al. 2018; Li et al. 2021). The presence of birds can be used as bioindicators to represent the biodiversity in an ecosystem within a certain area; this includes the mangrove forests because birds could occupy a different type of habitat, having dynamic mobility and also have an important role in the ecosystem food chain and ecological networks (Isworo and Oetari 2020). Regarding biodiversity assessments, birds are often used as biological indicators that are easy to observe, have versatile ecology, are well-known, and have a highly developed survey method (Arzel et al. 2015). In such cases, understanding the waterbird diversity and abundance is important to provide information to design conservation strategies on a regional scale (Dilrangi et al. 2021).

Roughly 80% of Madura Island, Indonesia, mangrove areas are in the Sumenep District (Muhsoni 2014). However, there are no data published regarding the waterbird diversity in Sumenep. A small note published in 2009 stated an observation of 71 endangered milky stork (*Mycteria cinerea*) in Nambakor fish ponds in Sumenep (van Balen et al. 2009). It suggests that the vast extent of the mangrove forest and its surrounding area in Sumenep District might provide an important habitat that holds a diverse number of waterbirds that are sometimes neglected. This study aimed to provide preliminary species checklists of waterbirds, as well as to assess species diversity and abundance of waterbirds around Ekasoghi mangrove area in Eastern Sumenep and to report an interesting finding of possible distribution extension of a certain waterbird species within Madura Island, Indonesia.

MATERIALS AND METHODS

Study area

This research was conducted in Ekasoghi mangrove area located in the eastern Madura Island, within the administration area of Tanjung Village, Saronggi Subdistrict, Sumenep District, East Java, Indonesia (Figure 1). The research area was then divided into three stations, representing different habitat types around Ekasoghi mangrove area. The first station is located on the shore around the perimeter of a mangrove forest with mudflats and rocky shallows that are exposed during low tide. The second station is behind the mangrove area, with a near-dried aquaculture pond bordering plantations. The third station was located in the eastern part of the mangrove area, on which the path of the inner mangrove forest, below the canopy, was selected as the third research station.

Thus, the first station has an open mangrove habitat, the second station has an open habitat with low tree cover, and the third station has a more closed habitat with lots of tree cover. These areas were selected to represent different ecosystems along the Ekasoghi mangrove area. Different types of habitat selected might affect the diversity of waterbird species in a given area, as different types of waterbirds utilize different parts of coastal wetlands to support their need to forage or rest (Krebs 2014; Khalil et al. 2021). This research was conducted during low tide in the morning, starting from 6.00-10.00 in West Indonesian Time (UTC+07:00) on 20 January 2024. This particular time was chosen because, in the morning, the waterbirds are actively locomoting or searching for food; thus, the chance of encountering the waterbirds is higher (Pettalolo et al. 2020).

Procedures

This research was conducted using the exploration method, where every bird encountered during the survey at each station was recorded. The observations were conducted at each station by walking through the observation path with an occassional pause around every 50 meters. The observation time for each observation point was around 15 minutes, with the total time for each station being around two hours. At the same time, the observer explored the research area or during a pause in a place with wide visibility (Triliantho et al. 2022). Using this method around the mangrove area, the observer could explore the outer perimeter of the mangrove area and stop at every potential place to observe the waterbirds or venture deep into the mangrove area during the low tide (Salahuddin et al. 2021). The waterbirds encountered during the survey were all recorded, and, if possible, a photograph was taken by a digital camera capable of capturing bird images from a long distance.

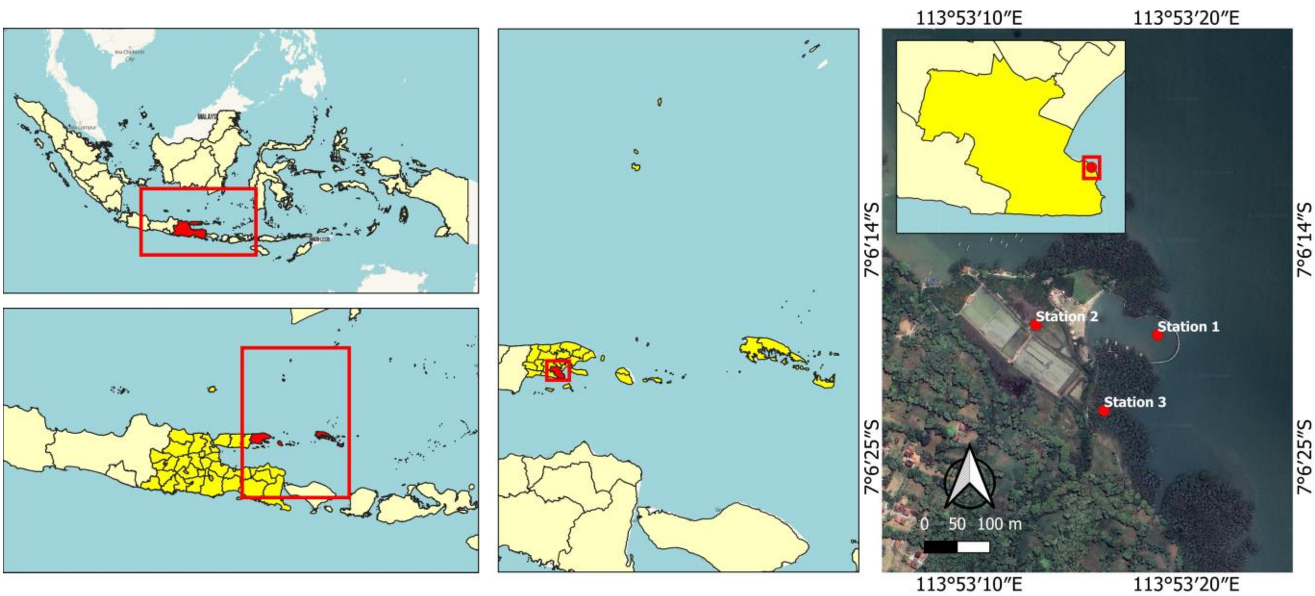

Figure 1. Location of Ekasoghi mangrove area, Sumenep District, East Java, Indonesia with every station, indicated with red dots on the map

The waterbird species identification was carried out by carefully examining the external morphology, voice, and behavior of the birds encountered during the survey (Kusmana et al. 2013). The bird species identification guide used to determine the waterbird species were the Field Guide on Birds of Indonesia Series 1: Greater Sunda (Taufiqurrahman et al. 2022), Birds of the Indonesian Archipelago: Greater Sundas and Wallacea (Eaton et al. 2016) and Shorebirds: An identification guide to the waders of the world (Hayman et al. 2011).

The protection status of the waterbird species refers to the Ministerial Regulation of Ministry of Environment and Forestry No. 106 Year 2018 on the Second Revision of Ministerial Regulation of Ministry of Environment and Forestry No. P.20/MENLHK/SETJEN/KUM.1/6/2018 on the Protected Species of Plants and Animals (Minister of Environment and Forestry 2018). Additionally, the conservation status of the waterbird refers to the IUCN Redlist 3.1 (IUCN 2023), and the migration and endemicity status of the waterbirds refers to the Birds of the Indonesian Archipelago: Greater Sundas and Wallacea (Eaton et al. 2016).

Data analysis

The waterbird species and individual data were tabulated according to each respective station. The data on the total waterbird species encountered were then used to count the Shannon-Wiener Diversity Index (Magurran 2013). The Shannon Wiener Diversity Index (H') was determined using the following formula:

$$H' = -\sum_{i=1}^{n} \frac{ni}{n} ln \frac{ni}{n} \quad (1)$$

Where H' is the Shannon-Wiener Diversity Index, *ni* is the sum of the individuals within the *i* species, *n* is the sum of the individuals from all species, and *ln* is logarithmic with a base *e* (Krebs 2014).

Species abundance data reflects species distribution on regional scales, so most biodiversity assessment research has focused on obtaining the species abundance data (Sun et al. 2020). The species abundance index was determined using the following formula:

$$Di = \frac{ni}{n} x100\% \quad (2)$$

Where *Di* is the species abundance index, *ni* is the sum of the individuals within the *i* species, and *n* is the sum of the individuals from all of the species (Ramadhani et al. 2022).

RESULTS AND DISCUSSION

Waterbird species composition

The identification of the waterbirds during this study resulted in the discovery of 38 individuals belonging to 15 species from 4 orders and 6 families (Table 1). The Charadriiformes order is the dominant one with the most species encountered during this study (60%). The nature of the Charadriiformes waterbirds causes this large proportion of them; this order is a large waterbird with a high species diversity. The Charadriiformes waterbirds inhabit, feed, and breed in wet areas from the coastal shores to the mountainous wetlands (McCain 2015). Most Charadriiformes members are gregarious species that live in flocks, where a large flock could contain more than one bird species (Greenebaum et al. 2014). At the same time, the lowest waterbird order in terms of the species number encountered during this study is Coraciiformes and Gruiformes, with only one species encountered for each order during this research.

Moreover, of all of the identified waterbird species in this study, two species (13,3%) are Indonesian Archipelago endemic, which are the cerulean kingfisher (*Alcedo coerulescens*) and Javan plover (*Anarhynchus javanicus*). At least eight species (53,3%) of the waterbird species are migratory species, which are gull-billed tern (*Gelochelidon nilotica*), Australian tern (*Gelochelidon macrotarsa*), Eurasian whimbrel (*Numenius phaeopus*), grey-tailed tattler (*Tringa brevipes*), wood sandpiper (*T. glareola*), common greenshank (*T. nebularia*), common redshank (*T. totanus*) and common sandpiper (*Actitis hypoleucos*), all of these species belong to the Charadriiformes order (Putra 2023). The Indonesian government protects two species of waterbirds: the Javan plover and the gull-billed tern (*G. nilotica*). While referring to the IUCN (International Union for Conservation of Nature) Redlist, almost all of the waterbird species encountered during this studi are categorized as Least Concern, except for one species, grey-tailed tattler (*T. brevipes*), categorized as Neat Threatened (IUCN 2023).

During this study, at least 19 non-waterbird species were recorded (Table 2), of which 11 species (57,8%) belong to the Passeriform order. There are two species of non-waterbird species, are scarlet flowerpecker (*Dicaeum trochileum*) and cave swiftlet (*Collocalia linchi*), that are endemic to the Indonesian Archipelago (Eaton et al. 2016). The only species encountered at every station during this study were the scarlet flowerpecker (*D. trochileum*) and the Pacific swallow (*Hirundo tahitica*). No protected non-waterbirds were encountered during this study, and all non-waterbird species are categorized as Least Concern.

Diversity and species abundance index

Diversity index analysis shows station I has the highest diversity index with 1.97, followed by station II with 1.95, and station III with the lowest diversity index with 1.33 (Table 3). The diversity index on each station signifies that the Ekasoghi mangrove area has a medium waterbird diversity, which falls under the medium criteria based on the diversity index value of more than 1 and less than 3 (Hidayat 2013). The higher diversity index value in a community within a certain area is suggested to signify the more complex relationship between community components (Harmoko et al. 2021). Generally, the fluctuation of the diversity index in a certain community is affected by six main aspects: observation time, habitat type diversity, inter-species/individual competition, predation, ecosystem stability, and productivity (Krebs 2014). Besides, other factors related to the observation activity also affect the diversity index value; for example, data collection method, study area, and habitat homogeneity are among the most important factors affecting diversity index output in a certain study area (Takele and Endale 2019). Specifically, the variations between birds' diversity index values in an area are more related to food availability (Adelina et al. 2016).

The waterbird species abundance index in Ekasoghi mangrove area shows that striated heron (*Butorides striata*) has the highest abundance index value (Table 4) at 18.42. Javan plover (*A. javanicus*) and common sandpiper (*A. hypoleucos*) have the second highest abundance index of 13.16 each. The abundance of waterbird species in a certain area relates to habitat conditions and food availability (Ramadhani et al. 2022). Furthermore, the abundance of waterbirds is also affected by the change in physical and chemical factors in wetlands habitat, which could affect the availability of organisms that depend on wetlands habitat, especially organisms that provide food sources to the waterbirds (Purify 2019). Waterbirds' diet mainly consists of benthic invertebrates that depend on phytoplankton availability; thus, the difference in water quality could affect the benthic invertebrate community as a food source and affect the abundance of waterbirds in an area (Manikannan et al. 2012).

Table 1. Waterbird species list encountered in Ekasoghi mangrove area, Sumenep District, East Java, Indonesia

Order	Family	Scientific Name	Vernacular Name	Station			Conservation Status	
				I	II	III	PP	IUCN
Coraciiformes	Alcedinidae	*Alcedo coerulescens**	Cerulean kingfisher	√	-	√	-	LC
Pelecaniformes	Ardeidae	*Ardea intermedia*	Medium egret	-	-	√	-	LC
		Butorides striata	Striated heron	√	-	-	-	LC
		Egreta garzetta	Little egret	√	-	√	-	LC
		Ixobrychus sinensis	Yellow bittern	-	√	-	-	LC
Charadriiformes	Charadriidae	*Anarhynchus javanicus**	Javan plover	-	√	-	√	LC
	Laridae	*Gelochelidon nilotica*	Gull-billed tern	√	-	-	√	LC
		Gelochelidon macrotarsa	Australian tern	√	-	-	-	LC
	Scolopacidae	*Numenius phaeopus*	Eurasian whimbrel	√	-	√	-	LC
		Tringa brevipes	Grey-tailed tattler	√	-	-	-	NT
		Tringa glareola	Wood sandpiper	√	√	-	-	LC
		Tringa nebularia	Common greenshank	-	√	-	-	LC
		Tringa totanus	Common redshank	-	√	-	-	LC
		Actitis hypoleucos	Common sandpiper	√	√	-	-	LC
Gruiformes	Rallidae	*Amaurornis phoenicurus*	White-breasted waterhen	-	√	-	-	LC

Note: *signify species endemic to the Indonesian Archipelago. Conservation Status, IUCN: NT: Near threatened, LC: Least Concern, PP: Protected by the Indonesian Government

Table 2. Non-waterbird species list encountered in the Ekasoghi mangrove area, Sumenep District, East Java, Indonesia

Order	Family	Scientific Name	Vernacular Name	Station			Conservation Status	
				I	II	III	PP	IUCN
Apodiformes	Apodidae	*Collocalia linchi**	Cave swiftlet	√	√	-	-	LC
Caprimulgiformes	Caprimulgidae	*Caprimulgus affinis*	Savannah nightjar	-	-	√	-	LC
Columbiformes	Columbidae	*Spilopelia chinensis*	Spotted dove	√	-	-	-	LC
		Geopelia striata	Zebra dove	√	-	-	-	LC
Coraciiformes	Alcedinidae	*Todiramphus chloris*	Collared kingfisher	√	-	√	-	LC
	Meropidae	*Merops philippinus*	Blue-tailed bee-eater	√	-	√	-	LC
Cuculiformes	Cuculidae	*Cacomantis merulinus*	Plaintive cuckoo	√	-	√	-	LC
		Cacomantis sepulcralis	Rusty-breasted cuckoo	√	-	-	-	LC
Passeriformes	Acanthizidae	*Gerygone sulphurea*	Golden-bellied gerygone	-	-	√	-	LC
	Aegithinidae	*Aegithina tiphia*	Common iora	-	√	-	-	LC
	Campephagidae	*Lalage nigra*	Pied triller	√	-	-	-	LC
	Dicaedidae	*Dicaeum trochileum**	Scarlet flowerpecker	√	√	√	-	LC
	Estrildidae	*Lonchura punctulata*	Scaly-breasted munia	-	√	-	-	LC
	Hirundinidae	*Hirundo tahitica*	Pacific swallow	√	√	√	-	LC
	Nectariniidae	*Anthreptes malacensis*	Brown-throated sunbird	-	-	√	-	LC
	Pycnonotidae	*Pycnonotus goiavier*	Yellow-vented bulbul	-	√	√	-	LC
		Pycnonotus aurigaster	Sooty-headed bulbul	-	-	√	-	LC
	Sylviidae	*Prinia inornata*	Plain prinia	√	-	-	-	LC
		Orthotomus sutorius	Common tailorbird	-	√	√	-	LC

Note: *signify species endemic to the Indonesian Archipelago, Conservation Status: IUCN: NT: near threatened, LC: Least Concern. PP: Protected by the Indonesian Government

Table 3. Waterbird species abundance index

Scientific Name	Vernacular Name	Abundance Index (Di)
*Alcedo coerulescens**	Cerulean kingfisher	7.89
Ardea intermedia	Medium egret	2.63
Butorides striata	Striated heron	18.42
Egreta garzetta	Little egret	7.89
Ixobrychus sinensis	Yellow bittern	2.63
*Anarhynchus javanicus**	Javan plover	13.16
Gelochelidon nilotica	Gull-billed tern	2.63
Gelochelidon macrotarsa	Australian tern	2.63
Amaurornis phoenicurus	White-breasted waterhen	5.26
Numenius phaeopus	Eurasian whimbrel	5.26
Tringa brevipes	Grey-tailed tattler	2.63
Tringa glareola	Wood sandpiper	7.89
Tringa nebularia	Common greenshank	2.63
Tringa totanus	Common redshank	5.26
Actitis hypoleucos	Common sandpiper	13.16

Table 4. Waterbird species diversity

Parameter	Stasiun		
	I	II	III
Diversity index (H')	1.97	1.95	1.33
Number of species	9	8	4
Number of individuals	16	17	5

Notes on the first record of Australian tern (*Gelochelidon macrotarsa*) in Madura Island

During the survey, two individuals of tern are observed and photographed. Both individuals are observed at Station I, soaring above the waters off the Ekasoghi mangrove area. Those observed terns have mostly white bodies with grayish primary wings, black legs, black bills, and black patches behind their eyes, signifying their non-breeding plumage (Eaton et al. 2016). However, further inspection conducted after the survey showed that both individuals belong to different species. The latter individual encountered has a larger bill and a thicker black patch behind its eye (Figure 2).

The description of the second individual observed based on the photograph evidence aligns with del Hoyo et al. (2014) and Eaton et al. (2016); within its non-breeding plumage, *G. macrotarsa* is distinguished from *G. nilotica* by its overall larger body, thicker bill, and larger, black ear coverts with the squarish end. The black mark on the *G. macrotarsa* runs continuously from the eye to the ear coverts, whereas in *G. nilotica affinis* (the Asian subspecies of Gull-billed tern) is slightly broken behind its eye or narrowly joined (Lilleyman and Hensen 2014). Both species are very similar because *G. macrotarsa* was formerly classified as a subspecies of *G. nilotica* under the name *G. nilotica macrotarsa* (Australian Bird Study Association 2020), on which, along with *G. nilotica affinis* were the only two subspecies of Gull-billed tern recorded in the Indonesian Archipelago (Eaton et al. 2016). After further assessment, *G. nilotica macrotarsa* was later separated as a distinct species, *G. macrotarsa,* based on its distribution and distinct morphological features (del Hoyo et al. 2014; Blaylock et al. 2020).

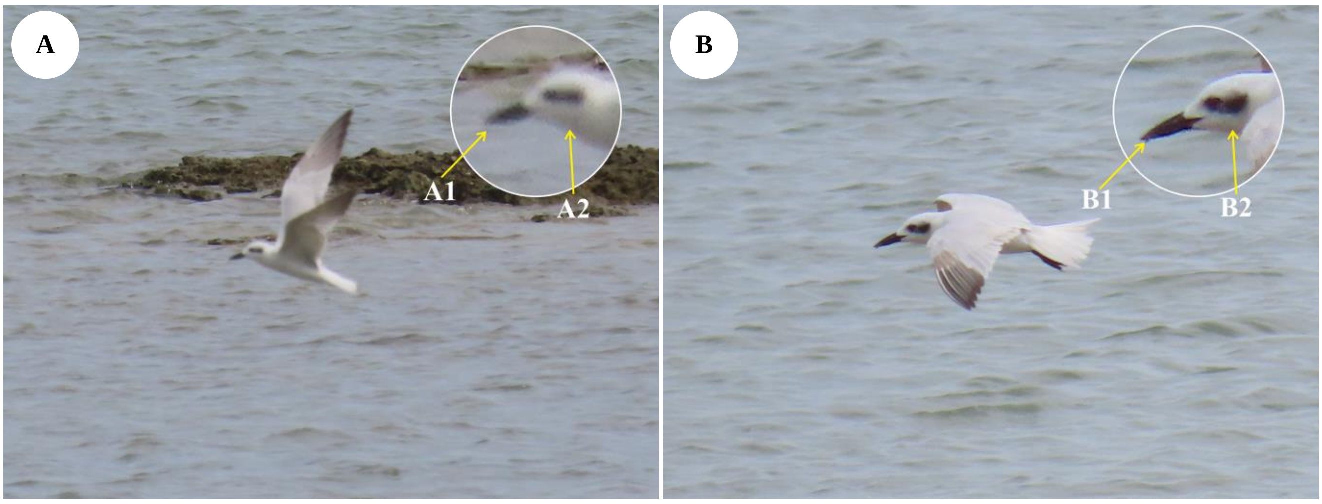

Figure 2. In-situ photograph taken during a survey of (A) Gull-billed tern *G. nilotica* and (B) Australian tern *G. macrotarsa* on their non-breeding plumage, highlighting the comparison of the beaks (A1 with B1) and black ear coverts (A2 with B2)

The first individual, *G. nilotica*, was observed flying and slowly scooping the water with its beak. This behavior indicates the feeding behavior of *Gelochelidon*, which feeds on shallows and mudflats, compared to other tern that plunge-dive into deeper waters to feed (Kushwaha et al. 2017). After that, this individual was observed to rest on the rocky shallows near mudflats. It is also observed to be the common daily routine of migratory waterbirds to feed on mudflats on low tide and roost when the tide is high (Lilleyman and Hensen 2014). Furthermore, for a brief moment, the latter individual, presumed to be *G. macrotarsa*, was observed flying on the same site above where the first individual was still visible. The latter individual is also photographed while the first individual rests on the rocky shallow tops. The latter individual flew for about 5 minutes and then flew away towards the east without doing the swooping behavior nor resting as the first individual did.

Discussion

The study revealed 15 waterbird species found in Ekasoghi mangrove area of Sumenep District, with an additional 19 non-waterbird species. Several similar studies conducted in other parts of Madura Island have successfully recorded 11 species of waterbirds belonging to 2 families (Charadriidae and Scolopacidae) and 1 Order (Charadriiformes) from Talang Siring Beach, Pamekasan District (Firmansyah et al. 2022), and 15 waterbird species belong to 6 families and 4 orders from four mangrove sites in South Bangkalan (Ramadhani et al. 2022). Moreover, this study and two other studies mentioned above recorded four species living in at least three regencies in Madura Island: Javan plover, common sandpiper, grey-tailed tattler, and Eurasian whimbrel. The Javan plover (*A. javanicus*) formerly had a limited distribution on Java and Bali Islands (MacKinnon and Phillips 1993). However, recent publications stated that this species' distribution extends as far as Timor Leste and South Sumatra, and the species also breed in these areas (Trainor 2011; Setiawan et al. 2019). The extension of Javan plover's distribution area is related to the availability of a suitable breeding habitat, where this species is known to inhabit a wet shortgrass area surrounded by fragmented, deeper water pools (Setiawan et al. 2019). Common sandpipers, grey-tailed tattlers, and Eurasian whimbrels are migrant species capable of traveling long distances and occasionally moving into safer habitats on their migration route (Ramadhani 2022; Putra 2023). These migratory waterbird species prefer wetlands habitats, such as mangrove areas, as this area could sustain their migration routes by providing a suitable habitat to feed and shelter from the extreme weather or from any threat that poses any danger to their survival (Ramadhani 2022; Seipalla 2020).

The Shannon-Wiener diversity index (H') is a formula to measure diversity that combines species richness and relative abundances (Dilrangi et al. 2021). The highest species diversity value is obtained at Station I, which has mudflats and rocky shallows habitat types on the edge of the mangrove forest. It has a more open habitat with plenty of shallow, watery areas for waterbirds to graze for food. Furthermore, the existence of the mangrove nearby with lots of vegetation provides sheltering for waterbirds that prefer to feed in a more shaded area (Dilrangi et al. 2021). The difference in the habitat structure and vegetation covers are the main factors providing habitat and food that affect the waterbird diversity index value around the mangrove area (Salahuddin et al. 2021). The diversity index values of stations I and II are similar because it has a similar species number and abundance compared to the diversity index value of station III. This similarity could be attributed to the habitat variation in Stations I and II, with plenty of open areas and adequate vegetation, than Station III which lacks open areas and dense vegetation. It is indicated that different habitat structures might increase waterbird diversity (Mohd-Azlan et al. 2015). During the survey, waterbirds from Scolopacidae and Charadriidae families were found in an open water habitat, wandering on the shallows for food. In comparison, the waterbirds from Alcedinidae and Ardeidae families were found perching on tree branches or man-made bamboo structures, such as bridges and floating mariculture structures around Ekasoghi mangrove areas.

The abundance index is related to the population size of waterbirds in an area (Ramadhani 2022). Furthermore, the waterbird abundance also reflects habitat quality, which signifies the abundance in food supply (Kleijn et al. 2014). In the Ekasoghi mangrove area, the striated heron has the highest abundance among the waterbirds found during this study. The striated heron is a cosmopolitan species in almost all tropical regions worldwide (Hayes et al. 2018). This species could be found in wide habitats, such as small streams, ponds, and marshes, where this bird generally hunts small fishes, frogs, and crustaceans for its main diet (McLachlan 2011). This bird is a nocturnal bird that actively hunts at night time or dusk (Yanuar et al. 2017). Striated heron is also known to have adapted to breed on a floating mariculture structure (Qaneer and Butcher 2013); such structures are also encountered in the Ekasoghi mangrove area, where this bird is also found perching on top of it. The other waterbirds' abundance, such as the common sandpiper and Javan plover, are related to their behavior. The common sandpiper is a species of waterbird that lives solitarily or in a small flock and is generally common throughout the year. It could inhabit many habitats, like coastal waters, mangrove forests, marshes, rice paddies, and even inland water bodies (Eaton et al. 2016). The Javan plover is a species of waterbird that is locally common in its distribution area and lives in a pair or small flock that inhabits coastal areas, shrimp ponds, and coastal marshes (Eaton et al. 2016). In some of its distributional range, Javan plover was also observed to feed and breed on a dried shrimp aquaculture pond (Iqbal et al. 2013).

This study also successfully records a sighting of Australian tern (*Gelochelidon marcotarsa*) outside its known natural range. Australian tern breeds on inland water bodies during the rainfall season, and frequent the northern coastal water of Australia during non-breeding season (Lilleyman and Hensen 2014). It is a fairly common species to be observed on the Northern Australian coastline, with small but regular sightings of gull-billed tern also being observed as non-breeding visitors (Lilleyman and Hensen 2014; Lilleyman 2016). However, in Indonesia, the Gull-billed tern is a fairly common migrant in Indonesian coastal waters, where it migrate to warmer areas during winter months in Australia (Eaton et al. 2014) and was recorded from every major island in Indonesia (GBIF 2023a). Furthermore, the Australian tern in Western Indonesia records is still limited, and the nearest records of this species were two records from Serangan Island, Denpasar, Bali (GBIF 2023b), which separated for about 233 km from Ekasoghi mangrove area. There were also dozens records of Australian tern sightings from the Lesser Sunda Islands and the Moluccas, but no single observation has been registered from Madura and Java (eBird 2023). Thus, it is concluded that this research also provides information on the extended migration range of Australian tern to Madura Island and East Java.

Based on this research conducted in Ekasoghi mangrove area on the eastern coast of Sumenep, Madura Island, 15 water birds were found, dominated by the waterbirds from the Charadriiformes order. Based on the data obtained during this study, it has a range of diversity index from the highest 1.97 to the lowest 1.33. Three species with the highest abundance index value are striated heron with an abundance index value of 18.42, followed by Javan plover and common sandpiper, tied on second pace with an abundance index value of 13.16. The stations with more open areas and adequate vegetation hold more species and individuals during this study. Mangrove forests are a haven for biodiversity, and it has a high level of productivity for a wide array of organisms that depend on their existence. Specifically, it also provides the necessity for waterbirds to feed, rest, and shelter during their migration.

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Diversity and first record of Porifera (sponges) from Gujarat Coast, India

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Abstract. *Sabapara Z, Poriya P. 2024. Diversity and first record of Porifera (sponges) from Gujarat Coast, India. Indo Pac J Ocean Life 8: 18-32.* The present study represents a significant milestone in understanding sponge diversity in the Gujarat Coastal area. This investigation identified 51 sponge species and classified them into 3 classes and 28 families. Amongst the reported species, 47 species belong to class Demospongiae, followed by Calcarea and Homoscleromorpha, with 2 species, respectively. Remarkably, 24 of these species were previously undocumented along the Gujarat Coastline, while two species, *Sycon grantioides* Dendy, 1916 and *Halichondria (Halichondria) tenuiramosa* Dendy, 1922 only reported from the Gujarat Coast in India. Our research involved exploring 11 sites along the coast, with the primary objective of documenting intertidal sponges and exploring valuable insights into their habitat preferences. The study also includes information on the distribution patterns of these species within the region. Except for a few bio-eroding boring sponges, most of the recorded sponge species exhibit an encrusting growth habit. They are typically found in habitats beneath the rocks, zoanthid beds, shallow rock pools, coralline beds, caves-crevices and in close association with other macrofauna and seaweeds. This diverse range of habitats suggests the adaptability and resilience of these sponges in various ecological niches along the Gujarat Coast. The finding of many new records highlights the necessity of ongoing study and conservation initiatives to protect the diverse marine biodiversity of the Gujarat Coastline.

Keywords: Diversity, first record, Gujarat, India, intertidal, Porifera, sponges

INTRODUCTION

The world's biodiversity is estimated at 8.7 million species (Sweetlove 2011), and about 18,000 new species are described yearly (Chapman 2009). The World Register of Marine Species (WoRMS) database indicates 242,000 known marine species known to the science world (Bouchet et al. 2023). However, the discovery rate of new marine species has continuously increased (Costello et al. 2012). This may be due to increased taxonomic effort, technological advances, the exploration of new habitats and locations, the application of molecular approaches, or a combination of these things. With at least the numbers of species found worldwide, poriferans, commonly known as sponges, are designated the most primitive of the multicellular animals with a most ancient geological history and are among the most diverse forms of sessile marine taxa. Sponge communities dominate many marine filter-feeding groups; they may create extensive garden-like ecosystems with great biomass and variety. In such environments, sponges influence the water quality and substrate condition and provide habitat and nutrition for many other organisms (Bell 2008). As effective filter feeders, sponges are essential in establishing a nutrient cycle that connects the pelagic environment to the benthos. They are also becoming more recognized as important providers of ecosystem services (Maldonado et al. 2005). Despite their evolutionary and ecological importance, sponges are not as well studied as corals and other benthic taxa that form structural habitats, and their importance within the global ecosystem is far less widely appreciated (Fromont et al. 2016).

The period from 1765 to 1892 is addressed as a remarkable era in the history of spongology, primarily attributable to the revolutionary contributions of scientists such as Carl Linnaeus, George Cuvier, Jean Lamarck, and other contemporary biologists; their pioneering efforts involved systematically categorizing various sponge groups, following in-depth studies on their physiology and phylogeny. In contrast, the exploration of the shallow water marine sponge fauna in peninsular India has been relatively limited. On the east coast, some investigations were conducted in Madras and Chilka Lake. Ali (1956) and Dendy (1887) dedicated their research to the sponge fauna of Madras, while Sivaramakrishnan (1951) delved into the development and regeneration of *Callyspongia diffusa* (Ridley, 1884) and *Tedania nigrescens* (Schmidt, 1862) from the Madras Coast. Further studies on the fauna of Chilka Lake in Orissa State were carried out by Annandale (1915). The major studies dealing with the deep-sea sponge fauna of the Bay of Bengal are those of Dendy and Burton (1926) based on the deep-sea sponges collected by R.I.M.S. "Investigator" and deposited in the Indian Museum, Calcutta. Kumar (1925) provided a comprehensive report on the sponges discovered during the exploration conducted by the Bengal Fisheries Steamer "Golden Grown." Burton and Rao (1932) studied shallow-water marine sponges from India, Burma, Sri Lanka, and the Andamans. Among the 82 species documented in their work, 12 species and 3 genera were identified as new.

Hozawa (1937) significantly contributed to the knowledge of calcareous sponges in the Bay of Bengal. Thorough research on the boring sponges of the Indian Seas has been conducted, with Thomas (1972) specifically examining coral-boring sponges in the Gulf of Mannar and the Palk Bay. Approximately 20 boring sponges have been identified infesting coral reefs in these areas. Notably, the fauna of the west coast of India has been studied less extensively than that of the east coast. Dendy (1915, 1916) contributed significantly to our understanding of the Gulf of Kutch's fauna, focusing on Calcarea and non-Calcarea collected by James Hornell in Okhamandal during 1905-1906.

However, after that, the study on the poriferan community is the least concerned on this coastline. Documenting local diversity is of the utmost importance in strengthening protection and management efforts in Gujarat, one of the country's key marine biodiversity areas. Therefore, the entire intertidal belt of this area has been thoroughly surveyed to assess intertidal sponges quantitatively.

MATERIALS AND METHODS

Study area

In the present study, the entire Gujarat Coastline, India, except the Gulf of Kutch, was surveyed comprehensively from ecological and biological points of view for its coast characteristics. Therefore, 11 locations (Table 1, Figure 1) of Gujarat's coastline were selected, encompassing different intertidal habitats such as rocky, sandy, rocky-sandy, rocky-muddy, and muddy shores. The basis for selecting these 11 areas were the differences between locations, the positions of slop, substratum type, and the intertidal zone length. The assessment of intertidal Porifera species diversity was done from June 2020 to July 2023. During this period, sampling sites were surveyed at monthly intervals.

Table 1. Collection Sites among the Gujarat Coasts of West India

Collection stations	G.P.S. coordinates	Site description
Okha	22°28'45"N 69° 4'43"E	Located between the tip of the Saurashtra coast and the Gulf of Kutch region of Gujarat state (India), the 4 km-long flat intertidal zone is a unique rocky shore with sandy patches.
Shivrajpur	22°19'25"N 68°56'23"E	'Blue Flag Beach' is located between Dwarka and Okha. The intertidal zone is 1 km long and has many rocks.
Dwarka	22°14'18"N 68°57'37"E	South-west part of Saurashtra coastline. 800 m long, sandy-rocky coastal area.
Antroli	21°12'54"N 69°39'54"E	Near Mangrol, around 1.5 km long intertidal zone with sandy patches and tide pools covered with sands and gastropod shells.
Loej	21°09'25"N 70°02'50"E	Near Mangrol, 1 km long flat intertidal coast
Mangrol	21°06'07"N 70°06'25"E	The coastal stretch is 3 km long, with a flat rocky substratum and boring sponge patches.
Veraval	20°55'02"N 70°20'26"E	Largest fish landing site, 3 km long intertidal belt with tide pools, puddles, crevices, small channels, flat rocky surface, coral, zoanthids, and *cerethium* assemblages. Smooth rock type at the upper zone of the coast.
Dhamlej	20°46'30"N 70°36'40"E	Near the Sutrapada, around 2 km long rocky substratum. Flat emergent rocky habitat covered by Zoanthus.
Simer (Simbor)	20°45'56"N 71°09'20"E	A small islet is located at the mouth of the Sahil River at the Bay of Simbor. Sandy-rocky coast with tidepools.
Diu	20°42'34"N 70°55'10"E	An island is located on the outer rim of the Gulf of Kambhat, a 2 km long intertidal coast with big rock pools.
Gopnath	21°21'36"N 72°10'14"E	Located on the coast of the Gulf of Khambhat near Bhavnagar

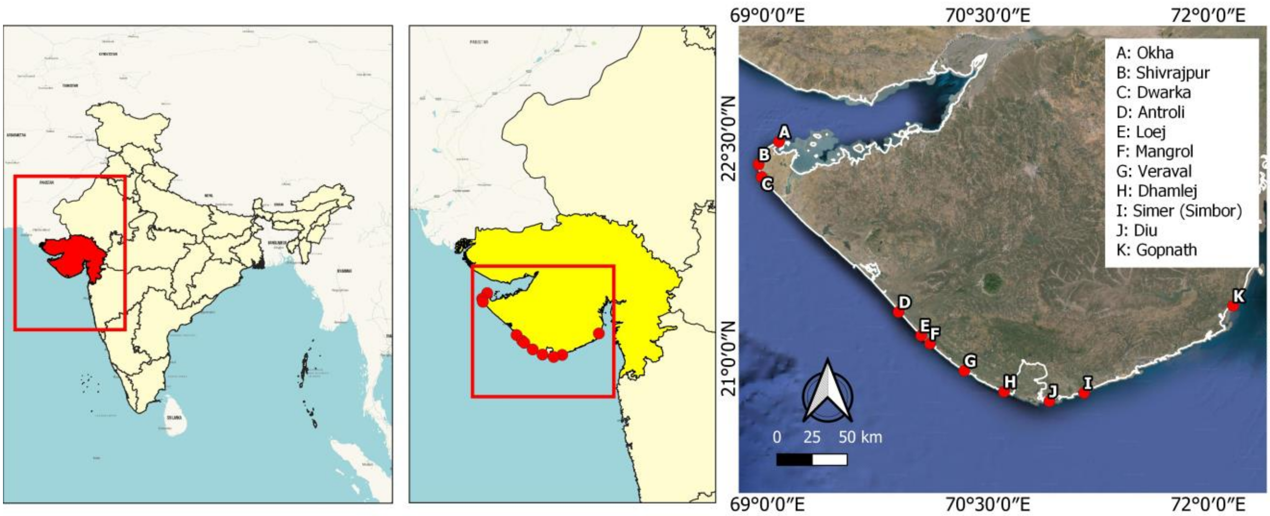

Figure 1. The map shows the sampling locations along Gujarat Coast, India

Field methods

By flipping the rocks and seaweed over, the study areas were extensively studied for the occurrence of sponges. In situ, photography, color, shape, texture, substratum type, and other morphological characters were recorded to identify sponge species. The complete study was conducted non-destructively, and the organisms were not disturbed. A few species of sponges were collected when necessary for identification.

Species identification methods

Collected sponges immediately fixed in 10% buffered formaldehyde for only a brief period. Back in the laboratory, preserved samples were examined under a Carl-Zeiss Stemi DV4 stereomicroscope fitted with a high-resolution CMOS camera, Lawrence & Mayo Image (Model: ISH300) microscope, and Magnus Plus Compound Microscope for morphological examinations and taxonomic analyses. Spicules slides were prepared by dissolving tissue in sodium hypochlorite and nitric acid solution. Identified specimen was transferred in 70-90 % alcohol and stored.

RESULTS AND DISCUSSION

A total of 51 sponge species belonging to 28 families, 15 orders, and 3 classes were recorded from 11 intertidal habitats of the Gujarat Coast (Figures 3-6 and Table 3). Among 51 species, 24 species are new records for the Gujarat Coastline. Most of the sponge species encountered belonged to class Demospongiae, with 47 species, followed by Calcarea and Homoscleromorpha, with 2 species, respectively. The highest diversity was observed on the Okha coast, which is located between the tip of Saurashtra coast and the Gulf of Kutch region of Gujarat state and 4 km long flat intertidal zone is a unique rocky shore with 35 sponge species, followed by Shivrajpur (31 species), a blue flag beach with 1 km long rocky intertidal zone, Dwarka (14 species) is south-west part of Saurashtra coastline with 800 m long, sandy-rocky coast, Antroli (11 species) has around 1.5 km long intertidal zone with sandy patches and tide pools covered with sands and gastropod shells, Loej (10 species) near Mangrol with 1 km long flat intertidal coast, Mangrol (13 species) coastal stretch 3 km long with flat rocky substratum and boring sponge patches, Veraval (18 species) largest fish landing site with 3 km long intertidal belt supported by coral, zoanthids and *Cerethium* assemblages, Dhamlej (8 species) near Sutrapada and around 2 km long rocky substratum. Flat emergent rocky habitat covered by zoanthus, Simer (Simbor) (9 species) is a small islet with a sandy-rocky coast, Diu (8 species) island located on the outer rim of Gulf of Khambhat; 2 km long intertidal coast with big rock pools and Gopnath (2 species) located on the coast of Gulf of Khambhat near Bhavnagar, Gujarat. (Table 2). Two species, *Sycon grantioides* Dendy, 1916 and *Halichondria (Halichondria) tenuiramosa* Dendy, 1922, were only reported from the Gujarat Coast in India. The present study has indicated that the intertidal areas of Okha and Shivrajpur are rich in diversity of sponges compared to the other coastal areas of the Gujarat Coastline. A variety of substrata influences the distribution patterns of sponges along intertidal habitats.

Habitat preference

The Gujarat Coastline is categorized into various types, including rocky, sandy, rocky-sandy, muddy, and muddy-sandy areas, as illustrated in Figure 2. Coastal regions exhibit diverse features such as platforms, crevices, caves, rock pools, coral pools, boulder areas, and sandy stretches. Vertical zonation is recognizable throughout the coasts. According to the specific ecological requirements, sponges dwell in various intertidal habitats, such as rocks, coral, shells, and other marine organisms. Existing macrofaunal assemblages also affect sponges' distribution patterns (Sabapara and Poriya 2023). As a result, a high richness of species is notable from the Okha to Dwarka coast, mainly because they have rocky and rocky-sandy coasts.

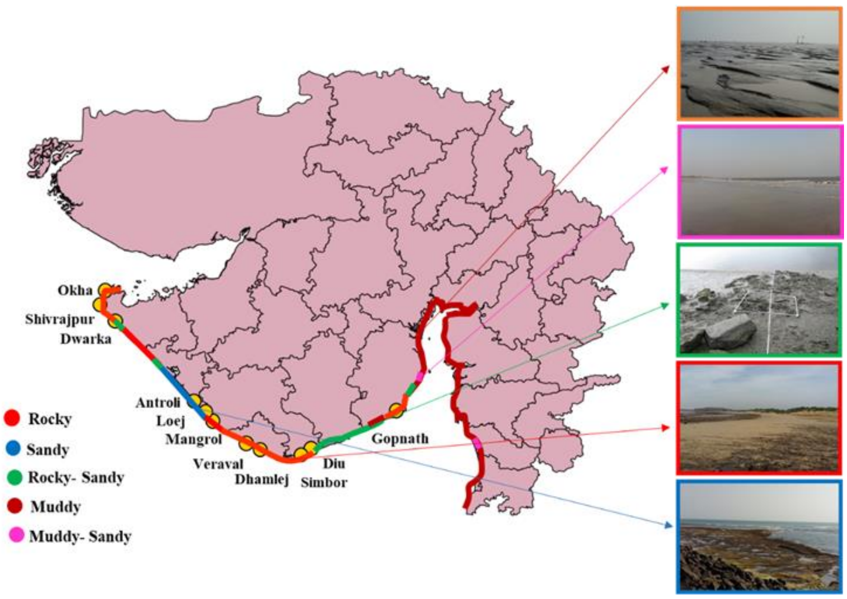

Figure 2. Coastal habitats of Gujarat, India

Table 2. Taxonomic account of sponge species reported from the Gujarat coast, India

Species	Gujarat											Previous report from India
	A	B	C	D	E	F	G	H	I	J	K	
Class: Calcarea												
Order: Clathrinida												
Family: Clathrinidae Minchin, 1900												
(1) *Clathrina coriacea* (Montagu, 1814)^	●	●				●						AD
Order: Leucosolenida												
Family: Syconidae Poléjaeff, 1883												
(2) *Sycon grantioides* Dendy, 1916									●	●		GU, MH
Class: Demospongiae												
Order: Dictyoceratida												
Family: Dysideidae Gray, 1867												
(3) *Dysidea avara* (Schmidt, 1862)	●						●					GU, MH
(4) *Dysidea fragilis* (Montagu, 1814)^	●	●										GoM, LD
(5) *Dysidea granulosa* Bergquist, 1965	●							●				LD
Family: Spongiidae Gray, 1867												
(6) *Hyattella tubaria* Lendenfeld, 1889^				●	●							GoM, LD
(7) *Hippospongia* sp.	●	●	●				●					GU, MH, GoM & TN, AD, LD
Order: Chondrillida												
Family: Chondrillidae Gray, 1872												
(8) *Chondrilla australiensis* Carter, 1873	●	●				●	●					GU, MH, GoM & TN, AD, LD
Order: Verongiida												
Family: Aplysinidae Carter, 1875												
(9) *Aiolochroia crassa* (Hyatt, 1875) ^	●											MH
(10) *Aplysina lacunosa* (Lamarck, 1814) ^	●											GoM
Family: Pseudoceratinidae Carter, 1885												
(11) *Pseudoceratina purpurea* (Carter, 1880)^		●										GoM, LD
Order: Haplosclerida												
Family: Niphatidae van Soest, 1980												
(12) *Amphimedon viridis* Duchassaing & Michelotti, 1864^	●	●	●	●			●					MH
Family: Callyspongiidae Laubenfels, 1936												
(13) *Callyspongia (Cladochalina) aculeata* (Linnaeus, 1759) ^	●											LD
(14) *Callyspongia (Cladochalina) diffusa* (Ridley, 1884)	●	●	●	●	●	●	●					GU, MH, GoM & TN, AD, LD
Family: Chalinidae Gray, 1867												
(15) *Haliclona (Gellius) cymaeformis* (Esper, 1806)						●		●	●			GU, MH
(16) *Haliclona (Gellius) fibulata* (Schmidt, 1862)	●	●										GU, MH, GoM & TN, AD, LD
(17) *Haliclona (Haliclona) oculata* (Linnaeus, 1759) ^	●											GoM
(18) *Haliclona (Reniera) cinerea* (Grant, 1826)	●	●	●				●					GU, MH
(19) *Haliclona (Reniera) tubifera* (George & Wilson, 1919)	●	●					●	●				GU, MH
Family: Petrosiidae van Soest, 1980												
(20) *Neopetrosia chaliniformis* (Thiele, 1899)^		●		●								GoM
(21) *Neopetrosia similis* (Ridley & Dendy, 1886)^	●											GoM
Order: Axinellida												
Family: Raspailiidae Nardo, 1833												
(22) *Raspailia (Clathriodendron) arbuscula* (Lendenfeld, 1888) ^	●	●	●				●					GoM
Order: Bubarida												
Family: Dictyonellidae van Soest, Diaz & Pomponi, 1990												
(23) *Acanthella cavernosa* Dendy, 1922^									●	●		GoM, LD
(24) *Acanthella ramosa* Kumar, 1925	●											GU, MH, GoM & TN, AD, LD
Order: Biemnida												
Family: Biemnidae Hentschel, 1923												
(25) *Biemna fortis* (Topsent, 1897)				●	●	●						GU, MH, GoM & TN, AD, LD

Order: Tetractinellida												
Family: Tetillidae Sollas, 1886												
(26) *Cinachyrella australiensis* (Carter, 1886)^	●	●	●	●	●	●	●	●	●	●	●	AM
(27) *Cinachyrella hirsuta* (Dendy, 1889)	●	●	●				●					GU, MH, GoM
Family: Geodiidae Gray, 1867												
(28) *Geodia* sp.		●										GoM
Order: Poecilosclerida												
Family: Isodictyidae Dendy, 1924												
(29) *Coelocarteria singaporensis* (Carter, 1883) ^	●								●			GoM
Family: Desmacididae Schmidt, 1870												
(30) *Desmapsamma anchorata* (Carter, 1882)	●	●				●						GU, MH, GoM & TN, AD, LD
Family: Iotrochotidae Dendy, 1922												
(31) *Iotrochota baculifera* Ridley, 1884		●										GU, MH, GoM & TN, AD, LD
Family: Mycalidae Lundbeck, 1905												
(32) *Mycale (Mycale) grandis* Gray, 1867^		●								●		GoM, AM
(33) *Mycale (Zygomycale) parishii* (Bowerbank, 1875)	●	●	●				●	●	●	●		GU, MH, GoM & TN, AD, LD
Family: Microcionidae Carter, 1875												
(34) *Clathria (Microciona) atrasanguinea* (Bowerbank, 1862) ^										●		GU, MH, GoM & TN, AD, LD
Order: Clionaida												
Family: Clionaidae d'Orbigny, 1851												
(35) *Cliona celata* Grant, 1826	●	●	●			●	●	●				GU, MH, GoM & TN, AD, LD
(36) *Cliona viridis* (Schmidt, 1862)	●	●		●	●	●	●					GoM & TN
(37) *Spheciospongia vagabunda* (Ridley, 1884)	●	●	●									GU, MH, GoM & TN, AD, LD
Family: Placospongiidae Gray, 1867												
(38) *Placospongia carinata* (Bowerbank, 1858)	●	●	●				●					GU, MH, GoM & TN, AD, LD
(39) *Placospongia melobesioides* Gray, 1867^			●	●	●							GoM
Order: Tethyida												
Family: Tethyidae Gray, 1848												
(40) *Tethya robusta* (Bowerbank, 1873)	●	●			●	●	●					GU, MH, GoM & TN, AD, LD
Family: Timeidae Topsent, 1928												
(41) *Timea* sp.	●	●										MH, GoM
Order: Suberitida												
Family: Halichondriidae Gray, 1867												
(42) *Halichondria (Halichondria) bowerbanki* Burton, 1930^	●	●	●	●	●	●	●	●				MH
(43) *Halichondria (Halichondria) tenuiramosa* Dendy, 1922		●										GU
(44) *Halichondria (Halichondria) panicea* (Pallas, 1766)	●	●	●	●	●	●	●	●	●	●	●	GU, MH, GoM & TN, AD, LD
(45) *Halichondria (Eumastia) sitiens* (Schmidt, 1870) ^									●			MH
(46) *Hymeniacidon perlevis* (Montagu, 1814)^									●	●		MH
(47) *Amorphinopsis excavans* Carter, 1887	●	●										GU, GoM
Family: Suberitidae Schmidt, 1870												
(48) *Pseudosuberites andrewsi* Kirkpatrick, 1900^	●	●										GoM
(49) *Suberites carnosus* (Johnston, 1842)	●											GU, MH, GoM, LD
Class: Homoscleromorpha												
Order: Homosclerophorida												
Family: Plakinidae Schulze, 1880												
(50) *Plakortis simplex* Schulze, 1880^	●					●	●					GoM
(51) *Plakina monolopha* Schulze, 1880^		●		●	●							GoM
Total number of species	35	31	14	11	10	13	18	8	9	8	2	

Note: X: All recorded stations; ^First record from Gujarat coast. Station Code and Names: A: Okha, B: Shivrajpur, C: Dwarka, D: Antroli, E: Loej, F: Mangrol, G: Veraval, H: Dhamlej, I: Simbor, J: Diu, K: Gopnath (Bhavnagar). GU: Gujarat, MH: Maharashtra, TN: Tamilnadu, GoM: Gulf of Mannar, AD: Andaman, LD: Lakshadweep

Table 3. Sponge diversity from Intertidal zones of Gujarat Coast, India

Species	Description
Family: Clathrinidae	
(1) *Clathrina coriacea* (Montagu, 1814)	Soft and delicate networks like a white color sponge were preferred. Several tubes join to share one common oscule. Habitat: Rock surfaces. Spicules are triradiates only with equal angles. Distribution: India, Britain and Northern Ireland, Norway, Spain, U.S.A., France, South Africa, Portugal, Jersey, Isle of Man
Family: Syconidae	
(2) *Sycon grantioides* Dendy, 1916	A tubular vase is like a white color sponge. Habitat: Zoanthid beds and shallow pools Spicules are triradiate mostly and oxea. Distribution: India
Family: Dysideidae	
(3) *Dysidea avara* (Schmidt, 1862)	Growth form encrusting with light rose-violet color. The surface looks like a three-dimensional network. Habitat: Underneath rocks The skeleton is made up of fibers. There are no mineral elements in the skeleton. Distribution: India, France, Spain, Italy, U.S.A., Australia, Turkey, Algeria, Papua New Guinea
(4) *Dysidea fragilis* (Montagu, 1814)	The growth form is irregular, 3-5 cm in diameter. The species is soft and fragile, with a brown-yellow color. The surface consists of an irregular network of dense collagen fibers. Habitat: Underneath rocks The skeleton is made up of spongin fibers. Distribution: India, UK and Northern Ireland, France, Spain, Jersey, Guernsey, U.S.A., Isle of Man, Portugal, Australia
(5) *Dysidea granulosa* Bergquist, 1965	Whitish-colored species are covered with fine conules, and their appearance is granular. Oscules are arranged in interval patterns and are 2-3.5 mm in diameter. Habitat: Caves and crevices on intertidal surfaces. The skeleton is made up of spongin fibers. Distribution: India, Australia, Indonesia, Palau, Papua New Guinea, Chinese Taipei, Thailand, China, Micronesia
Family: Spongiidae	
(6) *Hyattella tubaria* Lendenfeld, 1889	It is massive, with interconnecting tubular and brown-colored sponges. The surface is conulose. The consistency is firm, slightly elastic, and compressible. Habitat: Tide pools and puddles on the intertidal coast. The skeleton is made up of interconnecting Polygonal mesh fiber. Distribution: India, Singapore, Egypt, Indonesia, Seychelles, Vietnam, Yemen
(7) *Hippospongia* sp.	Black-brownish sponge with numerous oscules about 10-15 mm in diameter and irregularly distributed on the surface. Habitat: Attached to the hard substrates.
Family: Chondrillidae	
(8) *Chondrilla australiensis* Carter, 1873	Encrusting, glossy, and smooth brown sponge. Oscules are barely visible when the sponge is in water and look like tunicate. Habitat: Underneath rocks The skeleton comprises fibrillary collagen and a spheraster embedded in collagen. Distribution: India, Australia, Indonesia, Vietnam, South Africa, New Caledonia, Iran, Seychelles, American Samoa
Family: Aplysinidae	
(9) *Aiolochroia crassa* (Hyatt, 1875)	Purplish black color sponge with conulose surface. There is no visible opening. Habitat: Rock pools The skeleton is made up of spongin fiber. Distribution: India, Puerto Rico, Mexico, USA, Guadeloupe, Bonaire, Sint Eustatius and Saba, Martinique, Cuba, Cayman Island, Bermuda
(10) *Aplysina lacunosa* (Lamarck, 1814)	Tubular sponge with pinkish-purple color. The surface has irregular grooves. Habitat: Craves of intertidal flat The skeleton comprises a delicate and irregular network of spongin fiber. Distribution: India, Puerto Rico, Mexico, U.S.A., Cuba, Jamaica, Martinique, Brazil, Cayman Islands, Virgin Islands

Family: Pseudoceratinidae	
(11) *Pseudoceratina purpurea* (Carter, 1880)	Massive encrusting yellow-colored sponge with an uneven surface, scattered small, sharp conules, and prominent oscula. Habitat: Underneath rock and tide pools Spongin fibers scarcely develop, and the choanosome is collagenous. Distribution: India, Indonesia, Palau, Marshall Island, Seychelles, Singapore, Australia, Malaysia, Thailand, Mexico, U.S.A.
Family: Niphatidae	
(12) *Amphimedon viridis* (Duchassaing & Michelotti, 1864)	Dull green color sponge with repent branch and volcano-like oscules. Habitat: embedded in rocks on rock pools and growing between zoanthids polyps. Spicules oxea were slightly curved and robust type embedded in spongin fibers. Distribution: India, Puerto Rico, Mexico, U.S.A., Colombia, Jamaica, Venezuela, Brazil, Bermuda, Bahamas
Family: Callyspongiidae	
(13) *Callyspongia (Cladochalina) aculeata* (Linnaeus, 1759)	Violet colour sponge. Hollow tubular and rough irregular surface with a wide base. 6-8 tubes arising from a single wide base. Habitat: Underneath side of rocks in pools Spicules oxea type. Distribution: India, Atlantic Ocean, Caribbean sea, Pacific ocean
(14) *Callyspongia (Cladochalina) diffusa* (Ridley, 1884)	Pale yellow sponge with a soft, velvety texture. Surface reticulated and hispid. A branching sponge with tubes rises from a common base. Habitat: Crevices, Caves, tide pools, underneath rocks Spicules oxea, smooth, curved, and sharply pointed. Distribution: India, Australia, Indonesia, New Zealand, U.S.A., Sri Lanka, Myanmar, New Caledonia, Philippines, Palau
Family: Chalinidae	
(15) *Haliclona (Gellius) cymaeformis* (Esper, 1806)	Dark olive green color. Habitat: Crevices of rocks underneath rocks Spicules oxea type. Distribution: India, Australia, Indonesia, Hong Kong, China, Vietnam, New Caledonia, Papua New Guinea, Singapore, Malaysia
(16) *Haliclona (Gellius) fibulata* (Schmidt, 1862)	Light-pink color with a cushion like a sponge. Reticulation is showing through the surface. Habitat: Underneath rocks Spicules Straight and slightly curved oxea and sigma type. Distribution: India, France, Britain and Northern Ireland, Italy, Mayotte, New Caledonia, Portugal, Falkland Islands, Egypt
(17) *Haliclona (Haliclona) oculata* (Linnaeus, 1759)	Stalked and branching sponge with lilac color. Not hairy, neat oscules arranged serially along the edges of branches. Habitat: Vertical rock faces and fast-moving water areas. Spicules thick oxea type. Distribution: India, Britain and Northern Ireland, U.S.A., Canada, France, Netherlands, Guernsey, Sweden, Jersey, Germany
(18) *Haliclona (Reniera) cinerea* (Grant, 1826)	A purple-colored, soft, and flexible sponge with chimney-like growth of oscules. Slime appears when the sponge is pulled apart from the substratum. Habitat: Shallow pools and under rocks Spicules oxea type. Distribution: India, Canada, Britain and Northern Ireland, France, Korea, U.S.A., New Zealand, Japan, Egypt, Sweden
(19) *Haliclona (Reniera) tubifera* (George & Wilson, 1919)	Violet color sponge with oscular chimneys. Thin, long branching of the main body appears. Habitat: Tide pools, shallow pools with algae Spicules oxea type. Distribution: India, Venezuela, Belize, Mexico, U.S.A., Jamaica, Philippines, Panama, Martinique, Guadeloupe
Family: Petrosiidae	
(20) *Neopetrosia chaliniformis* (Thiele, 1899)	Chocolate yellowish brown color sponge. Hard and crumbly consistency. Habitat: Surface of substratum. Spicules are all oxea type with the same size. Distribution: India, Australia, Indonesia, Papua New Guinea, Thailand, Micronesia, Solomon Islands, Vanuatu, Palau, Seychelles, New Caledonia
(21) *Neopetrosia similis* (Ridley & Dendy, 1886)	Greyish blue color sponge. Habitat: Caves of rocks Spicules oxea slightly curved. Distribution: India, South Africa, Argentina, Australia, Heard Island and McDonald Islands, Tanzania, Indonesia

Family: Raspailiidae	
(22) *Raspailia (Clathriodendron) arbuscula* (Lendenfeld, 1888)	Bluish black arborescent and massive sponge. Branches of species conulated and evenly thick. Ostia scattered all over the body. Habitat: Underneath rocks mostly. Spicules mainly oxeas. Style, tylostyle, and acanthostyle are also present. Distribution: India, New Zealand, Australia
Family: Dictyonellidae	
(23) *Acanthella cavernosa* Dendy, 1922	A yellow sponge, its surface consists of blunt suculetion forms. The species is attached to the substratum by a small base. Habitat: Caves of rocks Spicules style, slightly curved style, strongyles type. Distribution: India, Australia, Indonesia, Seychelles, Papua New Guinea, Malaysia, China, New Caledonia, Thailand, Palau
(24) *Acanthella ramosa* Kumar, 1925	Orange color sponge with braches. Branches are thick at the base, and oscules are visible all over the body—small pointed conuli present. Habitat: found in flooded water Spicules oxea, style, vermiculoid, strongyle type. Distribution: India
Family: Biemnidae	
(25) *Biemna fortis* (Topsent, 1897)	Pale brown sponge. The surface is uneven and covered with sand. Habitat: Shallow sandy tidepools and rockpools Spicule style, sigma and rhapides types. Distribution: India, Indonesia, Malaysia, Micronesia, Seychelles, Thailand, Palau, Myanmar, Papua New Guinea, Singapore, China
Family: Tetillidae	
(26) *Cinachyrella australiensis* (Carter, 1886)	Bright yellow globular sponge. The surface has 1-4 porocalices covered with sand. Habitat: Mostly found in long periods of exposure to the flat surface of intertidal coast Spicule thin and long oxeas, acanthose, microxeas, sigmaspires. Distribution: India, Australia, Indonesia, Seychelles, Malaysia, Papua New Guinea, Mauritius, China, Egypt, Micronesia, Palau
(27) *Cinachyrella hirsuta* (Dendy, 1889)	Yellow globular sponge. Surface numerous porocalices with long spicules projecting outwards. Habitat: Flat surface and crevices of intertidal coast. Spicules are very long, straight oxea, very small, slender sigmaspires. Distribution: India, Philippines, Indonesia, Sri Lanka
Family: Geodiidae	
(28) *Geodia* sp.	White encrusting sponge with hispid surface. The surface is hard when touched. Habitat: Underneath rocks Skeletons possess crust of sterrasters
Family: Isodictyidae	
(29) *Coelocarteria singaporensis* (Carter, 1883)	Dark yellow-brown color. The surface is smooth, firm, and less compressible. Habitat: Flat surface of intertidal area covered with sand. Spicules Oxeas, strongyles, palmate isochela, toxa. Distribution: India, Australia, Indonesia, Papua New Guinea, Palau, Singapore, Thailand, Vanuatu, Marshall Islands, Malaysia, Solomon Islands
Family: Desmacididae	
(30) *Desmapsamma anchorata* (Carter, 1882)	Pale, slimy color. Oscules on elevation volcano-type tubes. Habitat: Shallow pools with sands underneath rocks Spicules oxeas sharply pointed type, anchorate chelae, sigmas. Distribution: India, Puerto Rico, USA, Mexico, Virgin Islands, Bonaire, Sint Eustatius and Saba, Guadeloupe, Martinique, Venezuela, Curacao
Family: Iotrochotidae	
(31) *Iotrochota baculifera* Ridley, 1884	Blackish, thin, encrusting sponge with a network-like appearance. Habitat: Underneath big rocks of intertidal area Spicules megascleres are absent; microscleres are birotulas. Network of heavy spongin fibre present. Distribution: India, Australia, Indonesia, Seychelles, Papua New Guinea, Micronesia, New Caledonia, Palau, Marshall Islands, Philippines
Family: Mycalidae	
(32) *Mycale (Mycale) grandis* Gray, 1867	Dark orange encrusting sponge. The surface is irregular, barely compressible, and brittle. Habitat: Crevices of rocks Spicules mycalostyle straight and slightly curved, anisochela, sigma ‘C’ and ‘S’ shaped and raphides types. Distribution: India, Indonesia, Thailand, U.S.A., Seychelles, Singapore, Australia, Marshall Islands, Netherlands, American Samoa, French Polynesia

(33) *Mycale (Zygomycale) parishii* (Bowerbank, 1875)	Dark orange color. The surface is membranous and uneven with spines; firm and slightly compressible. Habitat: Caves, flat algal substrates of intertidal area. Spicules mycalostyle, palmate anisochela, toxa, isochela, sigmas, microxea. Distribution: India, Australia, U.S.A., Thailand, Indonesia, Singapore, Madagascar, Brazil, Jamaica, Vietnam
Family: Microcionidae	
(34) *Clathria (Microciona) atrasanguinea* (Bowerbank, 1862)	Orange color encrusting and very thin sponge. Oscula is very minute. Habitat: Underneath rocks Spicules subtylostyle, acanthostyle, palmate isochelae, toxas. Distribution: India, Britain and Northern Ireland, France, Isle of Man, Egypt, Guernsey, Norway
Family: Clionaidae	
(35) *Cliona celata* Grant, 1826	Yellow color boring sponge. Large oscules with sieve-like openings. Habitat: On rock Spicules tylostyle and subterminal tylostyle. Distribution: India, United Kingdom of Great Britain and Northern Ireland, France, Spain, U.S.A., Portugal, Isle of Man, Guernsey, Netherlands, New Zealand
(36) *Cliona viridis* (Schmidt, 1862)	Brown color boring sponge. Smooth surface composed of firm and tough material. Habitat: Rock pools, caves Spicules tylostyle, spherasters type. Distribution: India, France, Spain, Croatia, Portugal, Italy, Greece, Egypt, Turkiye, Martinique, Mauritania
(37) *Spheciospongia vagabunda* (Ridley, 1884)	Orangish brown color sponge with a smooth surface. Habitat: Rocky-sandy pools. Underneath rocks. Spicules straight styles, tylostyles, slightly curved C-shaped spirasters Distribution: Australia, Indonesia, South Africa, New Caledonia, Papua New Guinea, U.S.A., Malaysia, Sri Lanka, Palau, Fiji
Family: Placospongiidae	
(38) *Placospongia carinata* (Bowerbank, 1858)	Brown color encrusting and hard sponge. Cortical plates make the upper layer. Habitat: Underneath rocks Spicules tylostyle, spirasters (microspined rhabds, slender-spined streptasters). Distribution: India, Mexico, Indonesia, U.S.A., Seychelles, South Africa, Colombia, Jamaica, Madagascar, Mauritius
(39) *Placospongia melobesioides* Gray, 1867	Chalky white color hard encrusting sponge. Cortical plates make an upper layer. Habitat: Underneath rocks Spicules tylostyle, selenasters, spheres. Distribution: India, U.S.A., Indonesia, Mexico, Papua New Guinea, Australia, Philippines, South Africa, France, Malaysia, Palau
Family: Tethyidae	
(40) *Tethya robusta* (Bowerbank, 1873)	Yellow golf ball-type sponge. The rooting processes or filamentous extensions are present. Habitat: Shallow pools Spicules spherasters types. Distribution: India, Indonesia, Australia, Israel, Mauritius, South Africa, Egypt, Solomon Islands, Seychelles, American Samoa, Christmas Island
(41) *Timea* sp.	Yellow-green color encrusting sponge. Surface hispid. Habitat: Underneath rocks Spicules tylostyle type.
Family: Halichondriidae	
(42) *Halichondria (Halichondria) bowerbanki* Burton, 1930	Olive brownish color. Encrusting and branching. Habitat: Flat surfaces, caves, crevices, underneath rocks Spicules Oxea only. Distribution: India, Britain and Northern Ireland, U.S.A., France, Korea, Netherlands, Canada, Isle of Man, Sweden, Portugal
(43) *Halichondria (Halichondria) tenuiramosa* Dendy, 1922	Pink color sponge. Long, slender, and almost straight branch. Habitat: Crevices of rocks underneath rocks Spicules Oxea type. Distribution: India, Tanzania, British Indian Ocean Territory
(44) *Halichondria (Halichondria) panicea* (Pallas, 1766)	Greenish, pale yellow color, encrusting sponge. The surface is minutely granular and breadcrumb-type. Habitat: Underneath rocks, tide pools, rock pools, caves, algal beds Spicules oxea and slightly curved oxea. Distribution: India, Britain and Northern, U.S.A., Ireland, France, Norway, Sweden, Netherlands, Canada, Germany, Jersey

(45) *Halichondria (Eumastia) sitiens* (Schmidt, 1870)	Off-white color sponge, densely covered with cone-shaped papillae, looks like branched or oscules. Habitat: Underneath rocks Spicules Oxea type. Distribution: India, U.S.A., Canada, Russian Federation, Svalbard and Jan Mayen, Egypt, Greenland, Iceland, Japan, Norway
(46) *Hymeniacidon perlevis* (Montagu, 1814)	Yellow color sponge. The surface has irregularly thin papillae. Habitat: Underneath rocks of pools All spicules style type. Distribution: India, United Kingdom of Great Britain and Northern Ireland, France, Spain, U.S.A., South Africa, Korea, Portugal, New Zealand, Isle of Man
(47) *Amorphinopsis excavans* Carter, 1887	A greenish-yellow sponge with massive growth form, its surface is opaque and convoluted. The oscules are not visible to the necked eyes. Habitat: Flat surface, tide pools Spicules large oxea type. Distribution: India, Australia, Indonesia, Myanmar, Malaysia, Seychelles, Vietnam, Egypt, Kuwait, Thailand, Oman
Family: Suberitidae	
(48) *Pseudosuberites andrewsi* Kirkpatrick, 1900	Pale-yellow color sponge. Oscules are small and irregular. The surface has a corrugated appearance. Habitat: Underneath rocks. Spicules tylostyle slightly curved. Distribution: India, Seychelles, Australia, Indonesia, Christmas Islands, Marshall Islands, Mauritius, Thailand, U.S.A.
(49) *Suberites carnosus* (Johnston, 1842)	Pinkish colour. Surface smooth-velvety feel. One oscula at the top of species. Habitat: On the rocks of pools Spicules tylostyle type. Distribution: India, United Kingdom of Great Britain and Northern Ireland, France, Italy, Australia, Isle of Man, Iceland, Norway, Croatia, New Zealand
Family: Plakinidae	
(50) *Plakortis simplex* Schulze, 1880	Thin, encrusting brown color sponge. The surface is smooth with scattered ostia. Habitat: Surface of intertidal area, Rock pools, and shallow pools. Spicules long shafted triene types. Distribution: India, Ireland, Reunion, Norway, Korea, New Caledonia, France, South Africa, Bermuda, Malaysia, Puerto Rico
(51) *Plakina monolopha* Schulze, 1880	The encrusting pale green-brown color sponge. Irregular lobate borders. Habitat: caves of rocks. Spicules triods and calthropses types. Distribution: India, Antarctica, France, New Zealand, United Kingdom of Great Britain and Northern Ireland, Saint Helena, Ascension and Tristan da Cunha, Canada, Cabo Verde, Italy, Madagascar

Sponges have specific habitat preferences influenced by water temperature, salinity, substrate type, and wave action. Studied sponges prefer stable hard substrates such as rocks, boulders, and shells for attachment; most encrusting sponges are found underneath rocks and crevices. The substrate provides a solid anchor for the sponges to attach and grow. Among the 51 species, they prefer different levels of wave exposure. Some species thrive in areas with high wave action, while others prefer more sheltered locations. The ability to withstand wave energy can influence the sponge's morphology and attachment strategy. Studied sponges are also adapted to tolerate periodic air exposure during ebb and water immersion during high tide. They need to withstand fluctuations in temperature, salinity, and desiccation. Some species like *Cinachyrella* sp., *Haliclona* sp., *Tethya* sp., and other upper intertidal sponges are more resilient to these changes than lower zone species.

Water quality, including factors like nutrient levels, dissolved oxygen, and water clarity, also affects the distribution of sponges. Among the recorded species, some species are found with algae and seaweeds in tide pools, while some papillate species thrive in the intertidal flat surface zones. Most recorded sponge species do not fluctuate because of temperature and salinity on the coasts; the ecological condition is stable for those species, but they are adapted to a wide range of conditions. Interactions with other organisms, including competition for space and other resources and predation, can influence the distribution and abundance of sponges. Species like *Haliclona (Reniera) tubifera* (George & Wilson, 1919) act as host organisms for the brittle stars for their protection, food, and shelter purposes and show mutualistic and obligatory commensalism relationships (Baroliya et al. 2023). Some species may have specific ecological niches or adaptations to avoid predation. Within the intertidal zone, sponges have specific microhabitats, which is why they are found in caves, crevices, tide pools, etc.


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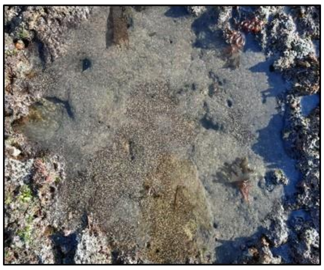

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Figure 3. Recorded sponge species from Intertidal zones of Gujarat Coast, India. Note: (1) *Clathrina coriacea*, (2) *Sycon grantioides*, (3) *Dysidea avara*, (4) *Dysidea fragilis*, (5) *Dysidea granulosa*, (6) *Hyattella tubaria*, (7) *Hippospongia* sp., (8) *Chondrilla australiensis*, (9) *Aiolochroia crassa*, (10) *Aplysina lacunosa*, (11) *Pseudoceratina purpurea*, (12) *Amphimedon viridis*, (13) *Callyspongia (Cladochalina) aculeata*, (14) *Callyspongia (Cladochalina) diffusa*, (15) *Haliclona (Gellius) cymaeformis*, (16) *Haliclona (Gellius) fibulata*, (17) *Haliclona (Haliclona) oculata*, (18) *Haliclona (Reniera) cinerea*, (19) *Haliclona (Reniera) tubifera*, (20) *Neopetrosia chaliniformis*, (21) *Neopetrosia similis*, (22) *Raspailia (Clathriodendron) arbuscula*, (23) *Acanthella cavernosa*, (24) *Acanthella ramosa*, (25) *Biemna fortis*, (26) *Cinachyrella australiensis*, (27) *Cinachyrella hirsuta*, (28) *Geodia* sp., (29) *Coelocarteria singaporensis*, (30) *Desmapsamma anchorata*, (31) *Iotrochota baculifera*, (32) *Mycale (Mycale) grandis*, (33) *Mycale (Zygomycale) parishii*, (34) *Clathria (Microciona) atrasanguinea*, (35) *Cliona celata*, (36) *Cliona viridis*, (37) *Spheciospongia vagabunda*, (38) *Placospongia carinata*, (39) *Placospongia melobesioides*, (40) *Tethya robusta*, (41) *Timea* sp., (42) *Halichondria (Halichondria) bowerbanki*, (43) *Halichondria (Halichondria) tenuiramosa*, (44) *Halichondria (Halichondria) panicea*, (45) *Halichondria (Eumastia) sitiens*, (46) *Hymeniacidon perlevis*, (47) *Amorphinopsis excavans*, (48) *Pseudosuberites andrewsi*, (49) *Suberites carnosus*, (50) *Plakortis simplex*, (51) *Plakina monolopha*

Discussion

Sponge fauna of India has been studied and documented by various researchers, including Thomas (1986, 1989), Dendy (1887), , Pattanayak (2006), Vinod et al. (2014), Immanuel et al. (2015), Pawar and Al-Tawaha (2017), Lakwal et al. (2018), George et al. (2020) and Pereira and Raghunathan (2020). They collectively reported approximately 486 sponge species. Extensive investigations into sponge diversity have been carried out, particularly in the Andaman and Nicobar Islands and South India. Gujarat, boasting the longest coastline in India, spanning about 1,600 km along the Arabian Sea, is a focal point for such studies. Gujarat's Coastal zones have varied marine ecosystems, including mudflats of the Gulf of Khambhat and the South Gujarat Coast, the rocky-sandy coast of Saurashtra peninsula, and coral reefs of the Gulf of Kutch. The tides in these areas are mixed semidiurnal type with a large tidal amplitude. The intertidal zone of this coastline has been extensively studied by various researchers for diversity and other ecological aspects of intertidal fauna by Misra and Kundu (2005); Vaghela et al. (2010); Gohil et al. (2011); Bhadja and Kundu (2012); Faladu et al. (2014); Joseph et al. (2014); Poriya and Kundu (2014); Raval et al. (2015); Chaudhari et al. (2016); Vakani et al. (2016); Beleem et al. (2017); Kachhiya et al. (2017); Baroliya and Kundu (2021); Gajera et al. (2022); Jethva et al. (2022). They studied particular organisms like mollusks, limpets, crabs, worms, echinoderms, etc. However, the spongology of this coast is poorly studied. Previously, in Gujarat, only two pioneer comprehensive studies on the diversity of sponges were available. One is based on Mr. James Hornell's collection from Okhamandal in Kattiawar between 1905 and 1906, published by Dendy (1916), and the other is by Thomas et al. (1996). Thus, the present work fills a crucial knowledge gap about the diversity of poriferans throughout the entire intertidal belt of this region after 1996.

The coastline of Gujarat State is known for its rich biodiversity due to its unique geographical location and varied habitat types. Sponges have notable ecological roles and are interesting subjects in pharmacological studies. The present study provides updated comprehensive reports of poriferan diversity from the Gujarat Coast after the last study by Thomas et al. (1996). Despite their widespread abundance and distribution, estimation of their global diversity poses a challenge because many still await description and proper taxonomic identification. There are only a few reports on the marine sponges of the Gujarat Coast, like Thomas et al. 1996, Kundu 2001, Poriya 2015, and Sabapara and Poriya 2023. Thomas et al. (1996) reported 24 sponge species from the Gulf of Kutch region, Gujarat. After that, Poriya (2015) reported 7 species, and Sabapara and Poriya (2023) noted 12 species from the Veraval coast of Gujarat. Altogether, 51 sponges were recorded, indicating rich poriferan biodiversity from this coastline. Calcarea and Homoscleromorpha are the two classes that represent the least in this inventory. Of the 51 species, 24 species are new records for Gujarat, which belongs to class demospongiae with 20 species, homoscleromorpha with 2 species *Plakortis simplex* Schulze, 1880; *Plakina monolopha* Schulze, 1880 and 1 species *Clathrina coriacea* (Montagu, 1814) from Calcarea. The number of species that occur from Okha to Gopnath coast shows geographical isolation, which could be attributed to habitat and coastal characteristics. Few species like *Halichondria (Halichondria) panicea* (Pallas, 1766) and *Cinachyrella australiensis* (Carter, 1886) were widely distributed, indicating their ubiquitous occurrences throughout the surveyed locations. Bio-eroding sponge species like *Cliona viridis* (Schmidt, 1862) and *Cliona celata* Grant, 1826 were also recorded, particularly within the small coral colonies that may play a vital role in the assemblage phenomenon (Pohler et al. 2022). For example, *P. simplex* shows a coast-specific distribution and is found distributed throughout the Mangrol coast intertidal zone due to big boulders supporting the underneath growth of this species. Notably, *P. simplex* prefers coral reef habitats (Varsha et al. 2020), and presently, it was only reported from the intertidal zones with small to large coral colonies (Poriya et al. 2014). The studied coast sponges mostly prefer rock pools, zoanthid beds, underneath rock, shallow pools, coralline beds, caves-crevices, and algal beds. Most observed sponges were also encrusting in nature, occurring in the cryptic habitats of caves and under surfaces of boulders. Under-surfaces of rocks and caves protect from temperature, water current, and other extremes, and trapping pools help reduce evaporation, thus reducing desiccation and salinity changes. The intertidal belts of the selected 11 locations differ mainly in slope, substratum types, and length of the exposed area during ebb. The tearing force of the tidal wave increased towards Diu from Okha (Misra and Kundu 2005), and the Gopnath coast has muddy zones that affect the sponge diversity. A greater effort dealing with the taxonomy of sponges in this diverse locality and the geographical isolation of the coasts will reveal the species distribution and other ecological aspects of Indian sponges.

Poriferans are taxonomically diverse, which presents challenges in their phylogeny and classification. Rich, diverse species of sponges are popular subjects in the pharmacological study. On the other hand, boring and intertidal sponge species receive relatively less attention despite their ecological roles in bio-erosion. The knowledge of species diversity on the west coast of India continues to increase, and the present study highlights the importance of Gujarat's significantly unnoticed sponge diversity, which underscores the critical importance of preserving and studying marine ecosystems, particularly in the face of ongoing environmental changes. Opportunities for an increased sampling effort and application of D.N.A. barcoding techniques, especially for species that are challenging to discriminate morphologically, will also help reveal the actual poriferan diversity in Gujarat. Moreover, barriers to reporting biodiversity data at a local scale must be identified and addressed to improve our current knowledge.

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Analysis of mangrove forest ecosystem sustainable management by coastal communities in Sampang District, Madura Island, Indonesia

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Abstract. *Koesdaryanto NSR, Wijayanti M, Simanjuntak MPD, Fathoni MFM, Sulton MN, Lillo EP, Kusumaningrum L, Indrawan M, Setyawan AD. 2024. Analysis of mangrove forest ecosystem sustainable management by coastal communities in Sampang District, Madura Island, Indonesia. Indo Pac J Ocean Life 8: 33-42.* The mangrove forest ecosystem is important in a coastal area to improve the welfare of coastal villages and increase the productivity of coastal ecosystems. This ecosystem has indicators of sustainability efforts, including ecological, economic, and social dimensions. This study aims to determine the sustainability status of mangrove forest ecosystems and compile recommendations in Taddan Village, Camplong Sub-district and Aeng Sareh Village, Sampang Sub-district, Sampang District, East Java, Indonesia. This research and data collection was carried out in December 2023. The methods used in data collection are interview techniques and questionnaire distribution. The primary data is processed with the Multidimensional Scaling (MDS) method through Rapid Appraisal for Fisheries (Rapfish), which displays Monte Carlo analysis, and the data results are aligned with previous literature studies. The results of the Rapfish analysis showed that the sustainability index of mangrove ecosystem management in the two villages included ecological dimensions (sustainability index of Taddan and Aeng Sareh Villages, respectively 62.88 and 21.05), economic dimensions (sustainability index of Taddan and Aeng Sareh Villages, respectively 35.78 and 40.14), and social dimensions (sustainability index of Taddan and Aeng Sareh Villages, respectively 42.94 and 39.51). Alternative strategy recommendations that can be applied for sustainable mangrove ecosystem management in Taddan and Aeng Sareh Villages, Sampang, are improving coordination between stakeholders, making patented regulations, training on creativity and productivity of village communities, formulating mangrove ecosystem management programs, routinely carrying out rehabilitation efforts, and increasing awareness from researchers.

Keywords: Coastal, mangrove ecosystems, Rapfish, strategy, sustainability

INTRODUCTION

Mangrove ecosystems in coastal areas are important for supporting the region's human life and living things (Sierra-Correa and Kintz 2015). The mutual interaction and interdependence between components in mangrove forests are called mangrove ecosystems (Irsadi et al. 2019). Abundant resources of good quality are important in biological processes and support the life of living things, especially in terms of biodiversity or biodiversity (Arifanti et al. 2022). Mangroves are one of the coastal ecosystems that require integrated handling. According to Carter et al. (2015), the priority of the approach is to meet basic human needs, provide sources of income, and develop a healthy living environment. Mangroves will not grow optimally in coastal areas without estuaries, while mangrove growth will be more optimal if they have large river estuaries and mud substrates (Kusmana 2014). This is evident from the distribution of mangroves in Indonesia, which are generally found on the East Coast of Sumatra, Kalimantan, the North Coast of Java, and Irian Jaya (Fikri et al. 2022).

Mangrove ecosystems provide various local and global benefits (Dabalà et al. 2023). These ecosystems are able to store carbon, support biodiversity, and support fisheries (Carrasquilla-Henao and Juannes 2017). Mangroves are an important habitat for marine animals because they are a place to find food (Carrasquilla-Henao et al. 2019). The main contribution of ecosystems to fisheries production tends to come from the primary productivity of phytoplankton, which generally lives in water and is associated with mangroves (Ickowitz et al. 2023). As a nature-based resource, Mangroves effectively reduce coastal flood risk (Menéndez et al. 2020), protect coastal areas during storms, stabilize coastal areas, and prevent erosion (Das 2020). Mangroves also have the potential to improve water quality before it reaches the ocean by absorbing nutrients and pollutants from stormwater runoff (MacDonnell et al. 2017).

Sampang District is located on the coast of Madura Island, Indonesia and has a fairly extensive mangrove ecosystem. Based on mangrove data in Madura by Muhsoni and Pi (2014), in a book entitled 'Persembahan

Prodi Ilmu Kelautan Universitas Trunojoyo Madura untuk Maritim Madura,' the land area of mangrove ecosystems in Sampang District is 915.3 hectares (6.1%) of the 15,118.2 hectares of total mangrove ecosystems area on Madura Island. However, based on these data, mangrove areas have also damaged land area of around 6,324.1 hectares (41.8%) due to mangrove ecosystem management problems. Effective mangrove management can be seen from the nature of open access, the absence of transfer of ownership and use rights to local communities, and the difficulty recognizing and comparing the values of long-term non-consumptive services (Suman 2019). Knowledge of the condition of distribution and density of mangrove forests is needed to plan mangrove forest management in the future, especially on Madura Island (Muhsoni and Pi 2014). Mangrove ecosystems in Madura face two major threats: land conversion into ponds (salt and fish) and the issuance of individual property rights that make it easier for individuals to change land functions and transfer property rights in coastal and mangrove areas (Mahmud 2023).

The coastal area in Madura consists of the north and south regions, both of which have considerable tourism potential; besides that, some beaches have become domestic mangrove tourist destinations (Ikhwan et al. 2021). Like other ecosystems in other areas, the mangrove ecosystem in Sampang District has faced ecosystem problems from various aspects such as ecology, socio-culture, and economy. Mangrove ecosystems are important because they can store large amounts of organic carbon; some mangrove ecosystems also have sediments rich in minerals that are good for the soil (Perera et al. 2018). The problems of mangrove ecosystems are closely related to changes in land used to make other land (Dwijaya et al. 2021). Land change in Sampang District for the creation of salt ponds impacts three important aspects of the mangrove ecosystem. In the ecological aspect, land clearing to create salt ponds can cause the loss of natural habitats and mangrove ecosystems (Cahyaningsih et al. 2022). In the socio-cultural aspect, land clearing impacts the lack of knowledge about local wisdom related to mangroves in the area (Reyes-Arroyo et al. 2021). In the economic aspect, this land clearing can reduce the loss of resources obtained from mangrove ecosystems (Fistiningrum and Harini 2021). This also impacts local communities' decreasing knowledge of managing crops from mangroves to be used as economic resources. Hence, this study aims to determine the sustainability status of mangrove forest ecosystems and compile recommendations in Taddan and Aeng Sareh Villages, Sampang, Madura, East Java, Indonesia.

MATERIALS AND METHODS

Study area

This study is located in residential areas adjacent to mangrove forests on the coast of Madura in December 2023 by conducting interviews with residents around the mangrove forests of Taddan Village, Camplong Sub-district and Song-Osong Beach in Aeng Sareh Village, Sampang Sub-district, District, Madura, East Java, Indonesia (Figures 1 and 2).

Data collection

The data types collected in this study are primary and secondary; primary data are obtained through respondent survey techniques by conducting semi-structured interviews with the public and key informants, while secondary data are obtained through literature studies. The community sample was determined based on the purposive sampling method of 32 respondents in Aeng Sareh Village and 32 in Taddan Village. Respondents were selected purposively with the criteria of respondents interacting more or less with mangroves because they know local environmental conditions and interactions with mangrove forests (Nyangoko et al. 2020). This study's total number of respondents amounted to 64 people (Table 1). In the Rapfish method, sustainability is shown qualitatively with established criteria, then represented in numerical analysis by a group of scored attributes grouped into several areas: ecological, economic, ethical, institutional, technological, and social (Jimenez et al. 2021). This study uses three dimensions of mangrove ecosystem sustainability: ecology with 8 attributes, economy with 7 attributes, and social with 8 attributes (Table 2).

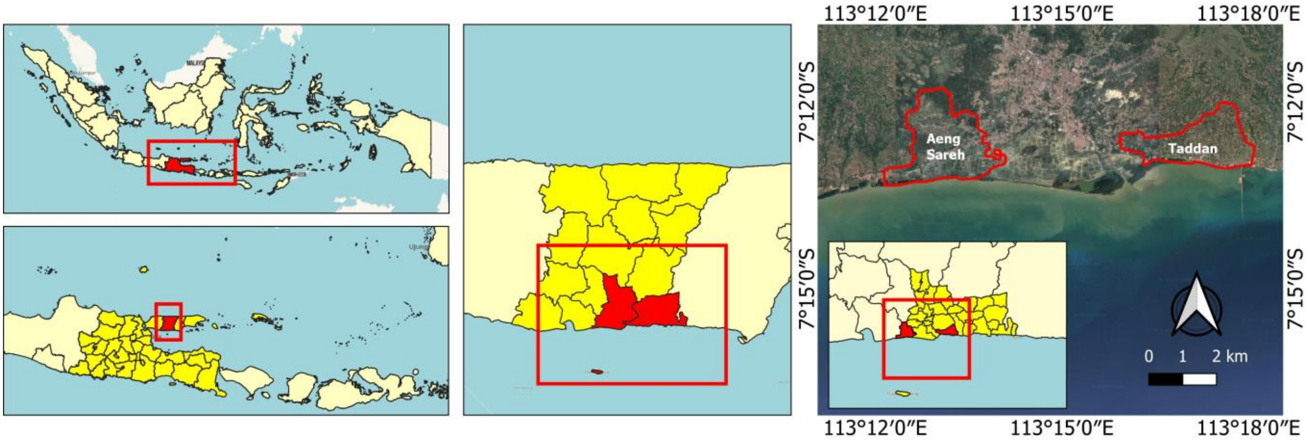

Figure 1. Map of the study area in Taddan Village, Camplong Sub-district and Aeng Sareh Village, Sampang Sub-district, Sampang District, East Java, Indonesia

Figure 2. Mangrove ecosystem in Sampang District, East Java, Indonesia. A. Taddan Village, Camplong Sub-district and B. Song-Osong Beach (Aeng Sareh Village, Sampang Sub-district)

Data analysis

The sustainability of mangrove ecosystem management was analyzed using Rapid Appraisal for Fisheries (Rapfish) software. This method is carried out by determining the attributes of each dimension (Adiga et al. 2016) that can represent the sustainability of mangrove ecosystem management. Multidimensional Scaling (MDS) methods is an exploratory and multivariate data analysis technique becoming increasingly popular. MDS is one of the multivariate data analysis techniques that tries to represent the higher dimensional data in lower space (Saeed et al. 2018). The dimensions and attributes that affect the sustainability of mangrove ecosystem management are determined based on regulatory reviews, assessments of experts such as practitioners and academics, and literature studies (Melo et al. 2020). Using the reference Yuliasamaya et al. (2021), this research uses three dimensions of sustainability: ecological, economic, and socio-cultural. Each dimension contains attributes that will be assigned values according to predefined criteria. We then categorize sustainability results into sustainability status (Table 3). An index value <25 indicates not sustainable, an index value between 25-50 indicates less sustainable, an index between 50-75 indicates quite sustainable, and an index between 75-100 indicates sustainable (Table 3). The next stage is a sensitivity analysis (attribute leverage) to see which attributes are the most sensitive in contributing to the sustainability index at the research site. Each dimension requires anomaly analysis that shows the sensitivity of each attribute on each dimension. This study examined the leverage factor from the Rapfish analysis, specifically from the highest Root Mean Square (RMS) value for each sustainability dimension (Chaliluddin et al. 2023). According to Kavanagh and Pitcher (2004), the leverage factor value for each attribute with an RMS of 2-6% has identical importance level. Consequently, we argue that an attribute in each dimension is sensitive if the RMS value exceeds than 6%. Then, the confidence level of sustainability index values of each multidimensional dimension was analyzed using Monte Carlo analysis. This analysis aims to see the effect of assessment errors on each attribute of each dimension, the influence of assessment variations, the stability of the MDS analysis process, data entry errors or missing data, and too high emphasizing values (Muksin et al. 2021). R square (RSQ) is the square of the correlation coefficient, which shows the proportion of variance from the optimization of data scaling contributed by the multidimensional scaling procedure that measures fit/accuracy (goodness of fit measure). The Stress value is the degree of ability to explain the results of the Multidimensional Scaling analysis. The difference between Monte Carlo and MDS reflects the status of sustainability. The difference value < 1 indicates that the value of the status of the sustainability index in the confidence interval according to the RSQ value shows that there is not much difference or means good value (Fadilah et al. 2021).

Table 1. Respondents profile table of Taddan Village, Camplong Sub-district and Aeng Sareh Village, Sampang Sub-district, Sampang District, East Java, Indonesia

Characteristic respondents	Taddan Village	Aeng Sareh Village
Gender		
Male	15	17
Female	17	15
Age		
15-30	5	3
31-45	17	15
46-60	7	8
>60	3	6
Level of education		
No formal education-Primary school	8	12
Junior high school	17	13
Senior high school-college	7	7
Occupation		
Farmer	4	11
Freelancer	5	5
Entrepreneur	6	4
Housewife	11	7
Truck driver	-	2
Laborer	2	3
Breeder	1	-
Unemployed	3	-

Table 2. Attributes of every sustainability dimension

Dimension	Attribute	Indicator	Sources
Ecology	Mangrove density	(0) sparse (< 1,000 trees /ha), (1) moderate (≥ 1,000 – 1,500 trees /ha), (2) very dense (≥ 1,500 trees /ha)	Pratiwi and Muhsoni 2021; Ainindya et al. 2024; *Field survey*
	Mangrove cover	(0) sparse (coverage <50%), (1) moderate (coverage ≥50 – 75%), (2) very dense (coverage ≥75%)	Aftsari et al. 2024; *Field survey*
	Mangrove pressure	(0) there is a change in the function of mangrove land without considering environmental functions, (1) there is a natural change in the area of mangrove land, (2) there is no decrease in the area of mangrove land	Aftsari et al. 2024; *Field survey*
	Mangrove diversity	(0) low (H' ≤ 1), (1) medium (1<H'<3), (3) high (H'>3)	Pratiwi and Muhsoni 2021; Tsani and Muhsoni 2022; *Field survey*
	Mangrove rehabilitation	(0) does not exist, (1) exists but is not managed well, (2) exists and is managed well	Aftsari et al. 2024; *Field survey*
	Fauna diversity of mangrove	(0) low (<2 types of fauna), (1) medium (2-10 types of fauna), (2) high (>10 types of fauna)	*Field survey*
	Salinity level	(0) low (EC 2-4 dS/m), (1) medium (EC 4-8 dS/m), (2) high (EC >8 dS/m)	Muhsoni 2020; *Field survey*
	Coastline changes	(0) decreases (abrasion), (1) remains constant, (2) increases (accretion)	Muhsoni 2020
Economic	Community income	(0) < average minimum wage, (1) = average minimum wage, (2) > average minimum wage	*Field survey*
	Mangrove zone	(0), not available, (1) available, but not yet complied with, (2) available and complied with	*Field survey*
	Mangrove utilization	(0) never, (1) sometimes, (2) always	*Field survey*
	Economic value	(0) low (<25% of total daily income), (1) medium (≥25 – 50% of total daily income), (2) high (>50% of total daily income)	*Field survey*
	Other income	(0) part time, (1) seasonal, (2) full time	*Field survey*
	Stakeholder involvement	(0) does not involve stakeholders, (1) involves several stakeholders, (2) involves various stakeholders	*Field survey*
	Utilization inventory	(0) not available, (1) available	*Field survey*
Social	Managing role	(0) low, (1) medium, (2) high	*Field survey*
	Citizen's awareness	(0) low (<50% of activities carried out), (1) medium (50-75% of activities carried out), (2) high (75-100% of activities carried out)	*Field survey*
	Local wisdom	(0) does not exist, (1) exists but is not efficient, (2) exists and is efficient	*Field survey*
	Citizen's knowledge	(0) low, (1) medium, (2) high	*Field survey*
	Level of education	(0) no school and elementary school, (1) middle school, (2) high school and university	*Field survey*
	Access to mangrove ecosystem	(0) have no access at all, (1) have poor access, (2) have good access	*Field survey*
	Destruction of mangrove	(0) low (cover reduced <25%), (1) medium (cover reduced 25-50%), (2) high (cover reduced >50%)	*Field survey*
	Utilization conflict	(0) a lot (>5 times/year), (1) some (2-5 times/year), (2) a little (<2 times/year)	*Field survey*

Table 3. Mangrove ecosystem sustainable category (Bakri et al. 2023)

Index value	Sustainability status
<25	Not sustainable
25-50	Less sustainable
50-75	Quite sustainable
75-100	Sustainable

RESULTS AND DISCUSSION

Sustainability status

Sustainability status is carried out by combining all dimensions, including ecological, economic, and social. Thus, 23 attributes were used to determine the sustainability status of mangrove ecosystem management in this study. The sustainability index values in these three dimensions can be visualized in triangular diagrams (Figures 3 and 4).

The triangle radar diagram depicts the sustainability status in an integrated manner between dimensions. In research conducted in Taddan Village, the value of the sustainability index on the economic dimension is 35.78; in the ecological dimension, it is 62.88; and in the social dimension 42.94 (Figure 3). This shows that the ecological dimension has a fairly sustainable status, and the social and economic dimensions in Taddan Village are less sustainable. In research conducted in Aeng Sareh Village, the value of the sustainability index in the economic dimension was 40.14, the ecological dimension was 21.05, and the social dimension was 39.51 (Figure 4). The results showed that the ecological dimension in Aeng Sareh Village is not sustainable, and the social and economic dimensions are less sustainable.

Moreover, the Monte Carlo value on all three dimensions in both villages is a good model because it has a value of <5 (Table 4). In research conducted in Taddan Village and Aeng Sareh Village, each dimension has a stress value of less than 0.25, meaning that the stress value analyzed using the MDS method is sufficient. This shows the accuracy of point configurations or goodness of fit models built for sustainability can represent good models. The smaller the stress value obtained, the better the quality of the analysis results (Dahliani and Maharani 2018). The Squared Correlation (RSQ) value of each dimension in this study is close to 1. Generally, if the Squared Correlation (RSQ) value is getting closer to 1, it shows the quality of the analysis results is improving. The difference value < 1 indicates that the value of the status of the sustainability index in the confidence interval according to the RSQ value shows that there is not much difference or means good value (Fadilah et al. 2021). Furthermore, an ordinal score to each attribute of 0 (lowest) and 3 (highest) for each attribute, and by Rapfish support, there are similarities or differences between each of the grouped attributes. Therefore, each attribute's sustainability level can be determined using the sustainability index. The attribute level that needs attention is also known based on the root mean square ordination percentage order (RMS). And evaluate the influence of errors using the Monte Carlo method.

Ecological dimension

Attributes that can determine the sustainability of mangrove ecosystems when viewed from the ecological dimension are based on eight attributes, namely (i) mangrove density, (ii) mangrove cover, (iii) mangrove pressure, (iv) mangrove diversity, (v) mangrove rehabilitation, (vi) fauna diversity of mangrove, (vii) salinity level, and (viii) coastal changes. The results of the leverage analysis show 2 attributes are most sensitive to ecological dimensions in both locations (Figure 5), namely mangrove diversity (RMS = 8.45) and mangrove rehabilitation (RMS = 6.36) in Taddan Village and mangrove fauna diversity (RMS = 11.53) and salinity levels (RMS = 7.73) in Aeng Sareh Village.

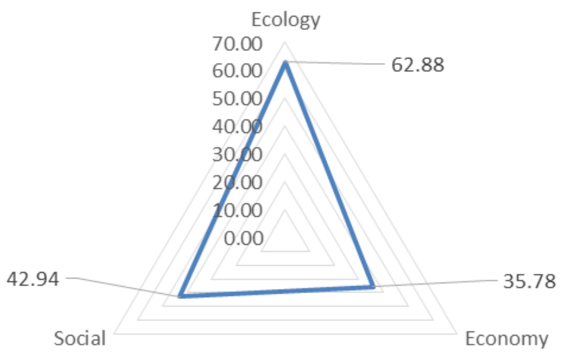

Figure 3. Sustainability index dimension in Taddan Village, Camplong Sub-district, Sampang District, East Java, Indonesia

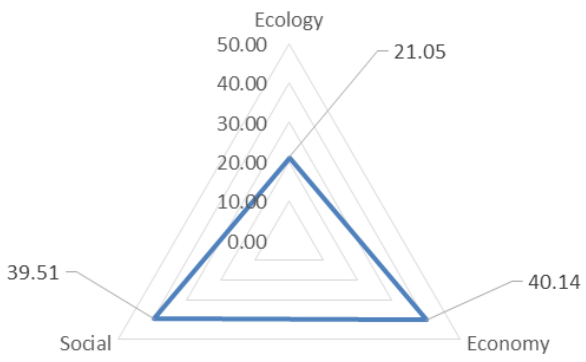

Figure 4. Sustainability index dimension in Aeng Sareh Village, Sampang Sub-district, Sampang District, East Java, Indonesia

Table 4. Sustainability index, Monte Carlo value, RSQ, and Stress value in Taddan Village, Camplong Sub-district and Aeng Sareh Village, Sampang Sub-district, Sampang District, East Java, Indonesia

Dimension	Sustainability Index	Monte Carlo Value	Difference	RSQ	Stress Value
Taddan Village					
Ecology	62.88	62.08	0.8	0.949571	0.13213
Economic	35.78	36.14	0.36	0.907535	0.195373
Social	42.94	43.66	0.72	0.884645	0.17625
Aeng Sareh Village					
Ecology	21.05	23.79	2.74	0.943764	0.133656
Economic	40.14	41.03	0.89	0.911163	0.188734
Social	39.51	40.3	0.79	0.901803	0.183514

Economic dimension

The determination of the sustainability status of mangrove ecosystem management on the economic dimension is based on seven attributes, namely (i) community income; (ii) mangrove zone; (iii) mangrove utilization; (iv) economic value; (v) other income; (vi) stakeholder involvement; and (vii) utilization inventory. Based on the results of the leverage of attributes chart (Figure 6) in Taddan Village, two attributes are most sensitive to the economic dimension: stakeholder involvement (RMS = 8.07) and economic value (RMS = 7.68). In comparison, the leverage of attributes chart results in Aeng Sareh Village display the two most sensitive attributes: community income (RMS = 7.82) and economic value (RMS = 6.62).

Social dimension

The attributes assessed on the socio-cultural dimension are eight attributes, namely (i) managing role, (ii) public awareness of the importance of mangroves, (iii) local wisdom, (iv) community knowledge about mangroves (v) community education level, (vi) community access to mangrove ecosystems, (vii) mangrove damage by the community, and (viii) utilization conflicts. Based on the results of leverage analysis shown in Figure 7, one attribute is sensitive to the value of the socio-cultural dimension in Taddan Village: mangrove use conflicts (RMS = 7.00). In comparison, two attributes are sensitive to the value of the socio-cultural dimension in Aeng Sareh Village: Access to mangrove ecosystem (RMS = 8.02) and level of education (RMS = 6.01).

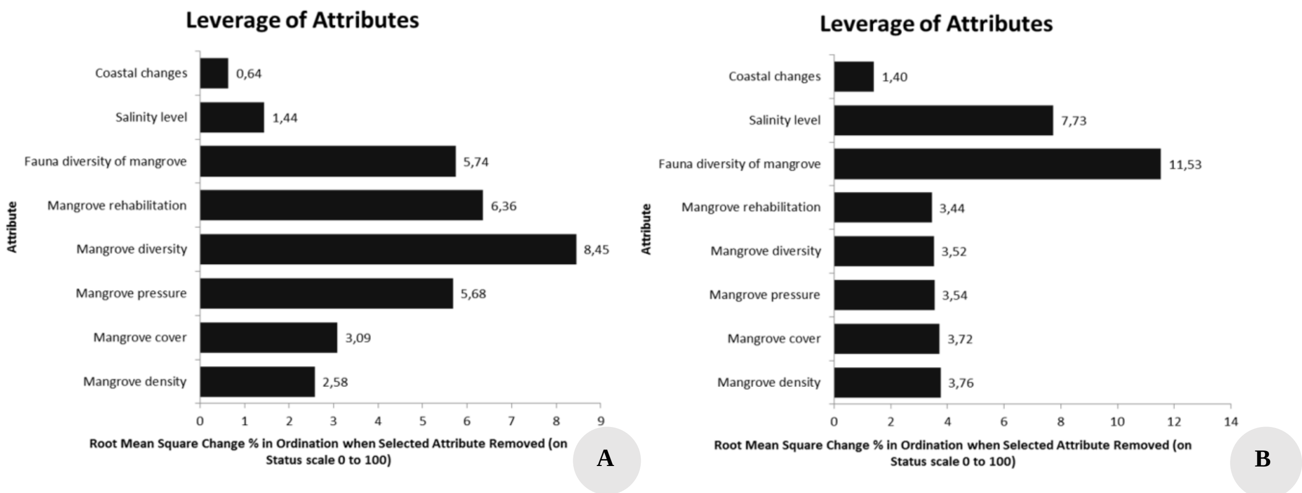

Figure 5. Leverage factor bar chart on ecological dimensions in A. Taddan Village, Camplong Sub-district and B. Aeng Sareh Village, Sampang Sub-district, Sampang District, East Java, Indonesia

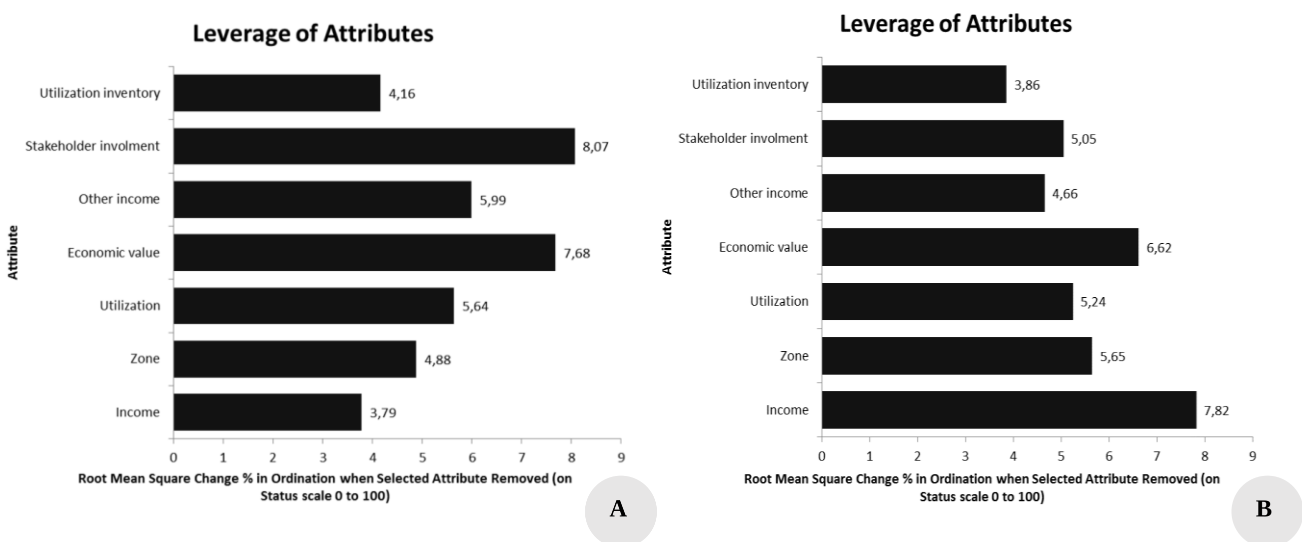

Figure 6. Leverage factor bar chart on economic dimensions in A. Taddan Village, Camplong Sub-district and B. Aeng Sareh Village, Sampang Sub-district, Sampang District, East Java, Indonesia

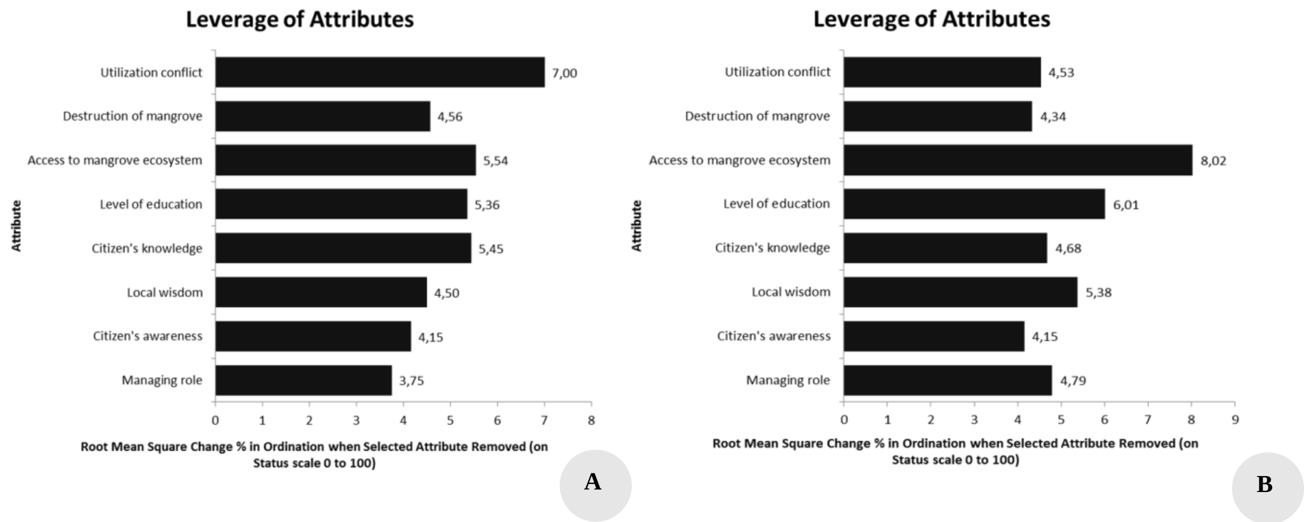

Figure 7. Leverage factor bar chart on social dimensions in A. Taddan Village, Camplong Sub-district and B. Aeng Sareh Village, Sampang Sub-district, Sampang District, East Java, Indonesia

Discussion

The ecological dimension of mangrove ecosystems is influenced by and affects various environmental aspects involved in these ecosystems. Mangrove ecosystems are unique and important coastal ecosystems that grow along tropical and subtropical coastlines. Sustainable management of mangrove ecosystems is necessary because many mangrove forests worldwide have suffered severe damage (Askar et al. 2021). In the ecological dimension, mangrove ecosystems have a role in maintaining biological integrity and marine resources around the ecosystem so that they can contribute significantly to other ecosystems around (Faridah-Hanum et al. 2019). The ecological importance of mangroves has been explained repeatedly, but globally between 2000 and 2016, mangroves were still lost with an annual average rate of 0.13% in several large countries (Su et al. 2021).

Land subsidence due to land clearing for new areas is a globally recognized problem, and land restoration that has been declining to date has become a major international agenda (Romijn et al. 2019). As with land decline, the decline in mangrove diversity and fauna diversity in mangrove ecosystems requires restoration and rehabilitation of the mangrove land itself (Su et al. 2021). In Aeng Sareh Village, many mangrove lands have been converted into salt ponds, which clearly impact various aspects of the mangrove ecological dimension. The role of the government and the community is needed for the rehabilitation of mangroves because mangroves have diverse ecological values, such as being able to produce natural resources that can be used for various needs and place to store carbon and reduce nitrogen levels in seawater (Jennerjahn 2020), and can be a safe reproductive habitat for many species of fauna such as fish, crabs, and mollusks.

The existence of mangrove ecosystems affects the surrounding community's economy through the potential of existing resources such as wood, food sources, cosmetic ingredients, dyes and tanners, and animal and bee feed sources (Andiny 2020). The location of mangrove forests adjacent to residential areas causes people to feel economic benefits directly related to meeting the community's needs for their survival. Economic activities carried out by the community on mangrove ecosystems can be detrimental if they are not regulated harmoniously with the environment (Raihan et al. 2021). Therefore, sustainable use of mangrove ecosystems must harmonize with resource usage management.

The RMS value obtained determines the magnitude of each attribute's role in maintaining status sensitivity, with higher RMS values showing more impact on sustainability (Hanifah et al. 2023). The lack of stakeholder and government involvement in maintenance activities and increasing the economic value of mangroves in Taddan Village is a factor that needs to be improved to create a sustainable mangrove ecosystem. In particular, village governments have an important role in the community's welfare through ponds on mangrove land (Velde et al. 2019). The use of mangroves for processed products can increase the productivity of local communities, so it has an impact on the economy and sustainability of mangroves. According to Razafindratsima et al. (2021), the diversification of mangrove-based food products reduces the burden of environmental degradation and further sharpens the ecological and economic functions of mangroves. In addition, careful planning related to utilizing mangrove potential into products with high selling value is needed while still paying attention to environmental aspects. Optimal and environmentally friendly resource utilization is an effort to preserve natural resources (Singgalen 2020).

The social dimension shows how the lives of local people which influence mangrove ecosystems, and the social dimension attributes show how the use of aquatic resources, especially mangrove ecosystems, affects the surrounding community or not (Noktasatria and Farid 2021). Therefore, managing mangrove ecosystem areas requires cooperation between communities and stakeholders to create a balance of ecosystems in mangrove areas (Pradana et al. 2023). In comparison, the cultural dimension emphasizes the importance of considering the benefits of culture for human well-being in making decisions because this dimension has many facets and is complex (Queiroz et al. 2017). The socio-cultural dimension shows the relationship between living things and other living things, and the existence of environmental problems is an amalgamation of human values and their management (Reyes-Arroyo et al. 2021).

The absence of restrictions on these resources shows the high access of local communities to mangrove ecosystems. To improve human welfare, improvements and wise management of mangrove ecosystems are carried out to obtain value benefits from these resources (Widayanti et al. 2023). However, if access to mangrove resources is allowed without clear regulations, it can negatively impact them. Mangrove resources will be damaged due to lack of proper management. The level of education of the people in Aeng Sareh Village is relatively low. If the community knows about mangrove ecosystems, mangrove management can run well. This is following the statement of Damastuti et al. (2023) that community involvement and increasing knowledge are determining factors for the success of mangrove rehabilitation and management. This is also follows research conducted by Yunus et al. (2023) based on the social dimension of the Biringkassi coastal mangrove area, high community access is seen from the many people who utilize mangrove areas by harvesting wood and fishing. However, freedom of access can be detrimental to the community in the mangrove. This is due to the lack of a sense of belonging to the survival of the mangrove ecosystem. Low levels of education lead to a lack of understanding, participation, and community responsibility for mangrove ecosystem management.

The increasing number of communities, followed by higher activity in utilizing mangroves and reduced resources, will trigger social conflicts. According to Wang et al. (2024), social conflicts can occur between communities or communities with governments. This conflict occurs due to limited resources but needs to increase continuously. Therefore, the available resources will continue to decrease if they are not managed properly. The existence of good access will make it easier for the community and other managers to monitor the management and review of mangrove locations easily (Akram et al. 2023). Community access in ecosystem management can affect the sustainability of mangrove ecosystems (Haris et al. 2021). Community access to management will lead to the role of the community in managing the ecosystem, conducting counseling, and mentoring for the community to be involved in protecting and maintaining mangrove ecosystems to create sustainable mangrove ecosystem management (Santoso and Nugraha 2019).

Based on the results obtained from the study, alternative strategy recommendations that can be applied for sustainable mangrove ecosystem management in Taddan and Aeng Sareh Villages, Sampang are improving coordination between stakeholders, making patented regulations, training on creativity and productivity of village communities, formulating mangrove ecosystem management programs, routinely carrying out rehabilitation efforts, and increasing awareness from researchers.

Based on the research, the sustainability management of mangrove ecosystems in Taddan Village and Aeng Sareh Village, Sampang District, it can be concluded: (i) The results of the Rapfish analysis in Taddan Village show the value of the sustainability index in the ecological dimension of 62.88, the value of the sustainability index in the economic dimension of 35.78, and the value of the sustainability index in the socio-cultural dimension of 42.94. (ii) The results of the Rapfish analysis in Aeng Sareh Village show a sustainability index value in the ecological dimension of 21.05, a sustainability index value in the economic dimension of 40.14, and a sustainability index value in the socio-cultural dimension of 39.51. Alternative strategy recommendations that can be applied for sustainable mangrove ecosystem management in Taddan and Aeng Sareh Villages, Sampang District, are improving coordination between stakeholders, making patented regulations, training on creativity and productivity of rural communities, formulating mangrove ecosystem management programs, routinely carrying out rehabilitation efforts, and increasing attention from researchers.

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Diversity of reef fish in the littoral zone of the south coast of Gunungkidul District, Yogyakarta, Indonesia

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[2]Department of Biology, Faculty of Science, Universiti Putra Malaysia. 43400 UPM Serdang, Selangor, Malaysia
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Abstract. *Rahma HS, Ayuningtyas HR, Nabila I, Annafi DN, Dianti, Yap CK, Dadiono MS, Setyawan AD. 2024. Diversity of reef fish in the littoral zone of the south coast of Gunungkidul District, Yogyakarta, Indonesia. Indo Pac J Ocean Life 8: 43-51.* Diversity in the intertidal zone plays an important role in the marine ecosystem. The balance of the intertidal zone's ecosystem and environmental health can be inferred from the diversity of fish. This study aims to identify reef fish species diversity in the intertidal zone of the south coast of Gunungkidul, Yogyakarta, Indonesia. The research was conducted on five beaches, i.e., Pringjono, Ngrenehan, Ngrawah, Torohudan, and Dadap Ayam, each with its own distinct ecological features. Survey and exploratory methodologies were utilized to analyze and reveal field findings. Observation and sampling were conducted using the random sampling approach. Data were analyzed using the Shannon Diversity Index (H'), the Evenness Index (E), and the Richness Index (Dmg). The study identified 1,378 individuals comprising 45 species and 28 families. The highest number of individuals was caught at Pringjono Beach, with 369 individuals. *Asterropteryx semipunctata* and *Bathygobius fuscus* from the Gobiidae family dominated most stations. The Diversity Index (H') indicated high species diversity across all stations, with the highest value of 3.562 and the lowest of 3.023. For the Evenness Index, most of the five stations were classified as almost evenly distributed, as the lowest value was 0.92 and the highest was 0.97. Meanwhile, the richness index of the fish species at the five research locations is a high category. In sampling stations, there are some differences in abiotic factors, such as salinity, water pH, water temperature, and Dissolved Oxygen (DO), which can affect the composition and distribution of reef fish in the littoral zone in Gunungkidul beach areas.

Keywords: Diversity Index, Evenness Index, fish abundance, reef fish population

INTRODUCTION

Marine ecosystems are among the most extensive and biodiversity-rich natural environments. Occupying about 71% of the planet's surface (Huo et al. 2020), marine ecosystems are home to millions of species, ranging from tiny microorganisms to giant mammals. Through complex interactions between living organisms and their environment, marine ecosystems play an important role in maintaining global ecological balance (Prakash 2021). Buonocore et al. (2021) emphasized that marine ecosystems provide oxygen, which is essential for life on Earth, and contribute to carbon sequestration. Biodiversity in marine waters encompasses a wide range of life forms, from stunning coral reefs to lush seagrass beds and deep oceans (Mooney et al. 2020).

The marine ecosystem of the intertidal zone on the south coast shows a high richness of diversity. The intertidal or littoral zone is the area between high and low tide (Dionfriski et al. 2021). This area periodically experiences fluctuating environmental conditions that include changes in temperature, salinity, and air exposure. Despite facing extreme conditions, the intertidal zone can support a diverse range of marine life that has explicitly adapted to thrive in such environments (Faria et al. 2021). In addition, ecosystems in the intertidal zone also play an important role in coastal ecology (Whitfield 2020). For many fish species, this zone is used as a refuge and food source. In addition, the intertidal zone also plays an important role in providing nutrients to the coastal ecosystem as a whole (Tuaputty et al. 2021). This role involves the process of nutrient cycling through the decomposition of organic matter and the movement of tidal waters that carry nutrients inland. The intertidal zone contributes significantly to shoreline stabilization (Bost et al. 2021).

The intertidal zone is inhabited by various marine animals, such as sea anemones, algae, snails, and small fish (Zulkifli et al. 2020). Diversity in the intertidal zone plays an important role in the marine ecosystem. The intertidal zone has diverse environmental factors, causing high species diversity and abundance (Sukiya and Putri 2015). The intertidal zone is a suitable habitat for various types of fish, especially reef ones (Maghfirah et al. 2023). These fish play a role in population control and movement patterns of other organisms in the intertidal area. Fishes that live in the intertidal zone will have unique characteristics that make them able to survive in a fairly extreme environment (Blewett et al. 2022; Binsasi and Hanoe 2023).

The intertidal zone in Gunungkidul Beach, Indonesia, provides a diverse habitat that can support various life for many fish species. The intertidal zone in the Gunungkidul Beach area has good biodiversity. Hobohm et al. (2021) state that rock formations, puddles, and algae vegetation, such as those in the Gunungkidul Beach area, characterize the dynamic and diverse intertidal zone. By knowing the diversity of fish, it can also be known how the ecosystem and environmental health in the intertidal zone are balanced. This research is expected to provide an understanding of the ecology of the intertidal zone. It can be used as a reference for developing more effective conservation and fish management strategies in the intertidal zone, especially on the five beaches studied. Conservation strategies include water quality monitoring, habitat protection, law enforcement, and collaboration with local institutions. This study aims to identify the diversity of reef fish species in the intertidal zone at five beaches in Gunungkidul, Yogyakarta, especially at Pringjono, Ngrenehan, Ngrawah, Torohudan, and Dadap Ayam. With this research, the intertidal zone at the five beaches can be given more attention to maintain its quality.

MATERIALS AND METHODS

Study area

This research was conducted in March 2024 at five beaches as observation stations, namely Pringjono Beach, Ngrenehan Beach, Ngrawah Beach, Torohudan Beach, and Dadap Ayam Beach, in Kanigoro Village, Saptosari Sub-district, Gunungkidul District, Yogyakarta, Indonesia (Figure 1). These five beaches were chosen because there has been no research on fish species in the intertidal zone, and such research is necessary for coastal conservation. The coordinates of each beach are as follows: Pringjono Beach as Station 1 (8°07'02.0"S, 110°29'58.2"E), Torohudan Beach as Station 2 (8°07'15.6"S, 110°30'51.4"E), Ngrawah Beach as Station 3 (8°07'27.9"S, 110°31'12.4"E), Dadap Ayam Beach as Station 4 (8°07'12.8"S, 110°30'27.1"E), and Ngrenehan Beach as Station 5 (8°07'15.6"S, 110°30'51.4"E). The selection of these five beaches as research stations was based on the beaches having coastlines and intertidal areas dominated by white sand and corals. The research locations represent the beaches in Kanigoro Village to obtain information on fish species diversity in the intertidal area of the coral beach. The lack of references that raise the biodiversity of fish in the intertidal area in the five beaches is a reference for the author to conduct this research.

Data collection and identification

The data collection method was carried out by direct observation at the research location and fish sampling. The method was employed along the coastline and towards the sea (±25 meters) in the intertidal zone during low tide, with three repetitions at each data collection point on every beach. The researchers focus on dividing each beach into three points: the right side, the center, and the left side. However, in practice, the researchers focus more on the sides with coral reefs along the beach. It is related to the presence of fish that tend to be found around coral reefs. Data collection was mainly carried out at low tide, but was also carried out before the low tide and after the low tide before the water fully rises. The survey method is used to obtain a representative of aspects of fish population dynamics (Tangke 2014). The exploratory method is a research method that examines and reveals findings from the field, allowing for the creation of models and drawing conclusions (Masserschmidt 1995). The method used for observation and sampling is the random sampling method, which is a sampling method in which each member of the population is given an equal opportunity to be selected as a sample (Noor et al. 2022). Fish were caught using fishing nets, fish traps, and fishing rods. Fish samples captured are photographed in the field using a fisheye lens, cameras, and scale mat. Underwater cameras were also utilized in data collection in this study.

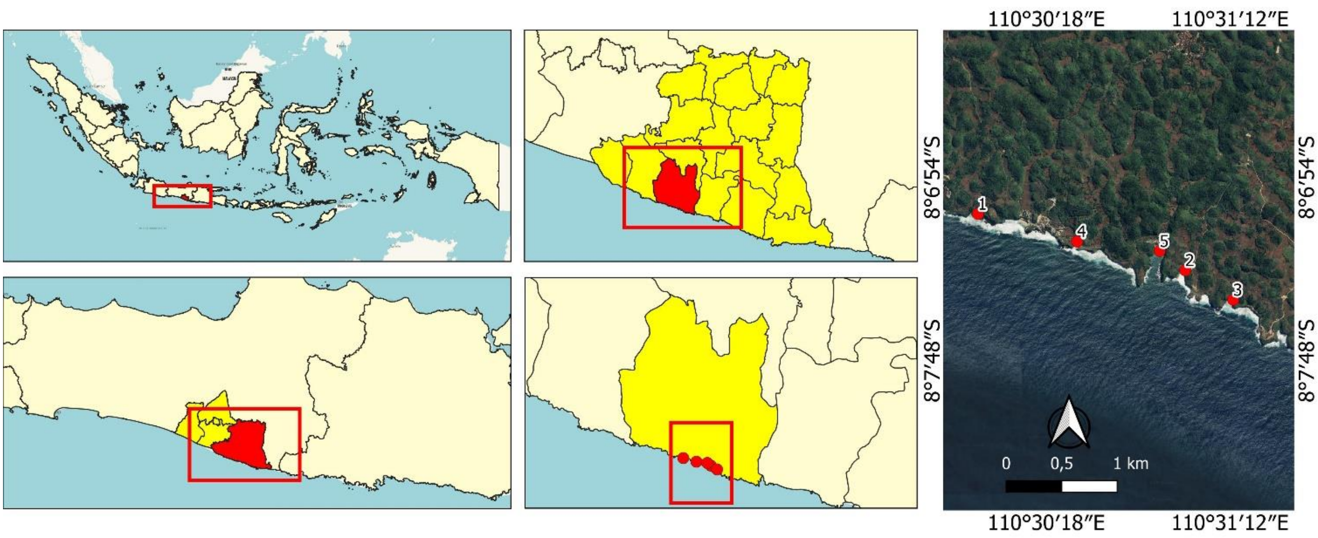

Figure 1. Sampling locations in the south coast of Gunungkidul District, Yogyakarta, Indonesia, i.e., Pringjono Beach (Station 1), Torohudan Beach (Station 2), Ngrawah Beach (Station 3), Dadap Ayam Beach (Station 4), and Ngrenehan Beach (Station 5)

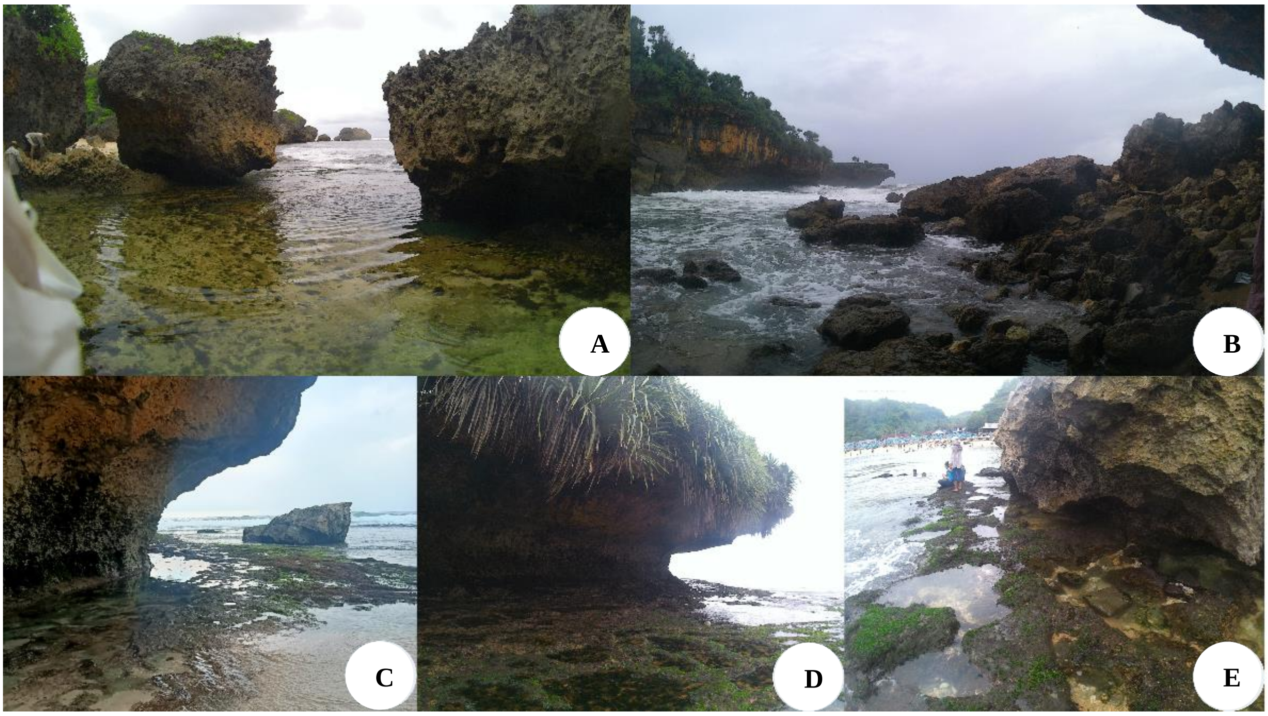

Figure 2. Intertidal zone substrate in the south coast of Gunungkidul District, Yogyakarta, Indonesia: A. Pringjono Beach, B. Torohudan Beach, C. Ngrawah Beach, D. Dadap Ayam Beach, E. Ngrenehan Beach

Measurements of abiotic factors were also taken at each research station at the same time as fish sampling when the beach is at low tide. On the first beach, the data collection was carried out on the first day at around 1 pm. The second beach was carried out on the following day at around 9 am, the third beach was taken at noon at 2 pm, then the fourth beach was taken the following day at around 10 am, and the fifth beach was taken at noon at around 2 pm. Measurement of abiotic factors at each station is carried out by measuring physical and chemical factors of water, which include salinity, pH of water, water temperature, and Dissolved Oxygen (DO). The tools used in the measurement of abiotic factors are refractometers to measure salinity, DO meters to measure dissolved oxygen, and pH meters to measure pH and water temperature. Fish samples were identified by local name, scientific name, and family. Fish samples were identified using several references such as books (Status and Trends of Coral Reefs of the Pacific), journals, the GBIF (Global Biodiversity Information Facility) website (2024), and the International Union for Conservation of Nature (IUCN) website (2024).

Data analysis

Data on species and the number of individuals (N) obtained at each station were analyzed using the Shannon Diversity Index (H') to estimate the diversity of fish species, the Evenness Index (E) to describe the similarity of the abundance of different species in a community, and the Richness Index (Dmg) to determine the level of species richness.

Shannon-Wiener Diversity Index (H')

According to Odum (1971), diversity (H') is used to explain the number of individuals of each species in a community. Fish diversity was calculated using the Shannon-Wiener Index based on Shannon and Weaver (1949).

$$H' = -\sum_{i=1}^{i} pi \ln pi$$

Where:
H' : Shannon-Wiener Diversity Index
Ln : Natural Logarithm
ni : Density of each type i
N : Density of all species
Pi : $\left(\frac{ni}{N}\right)$

Diversity criteria based on (Ludwig and Reynolds 1988; Sinaga et al. 2022): H'>3: high diversity; 1≤H'≤3: moderate diversity; 2 <H': low diversity

Evenness Index (E)

According to Odum (1971), the Uniformity Index (E) determines the similarity of the distribution of the number of individuals of each species at the community level. The Evenness Index can be calculated using the formula.

$$E = \frac{H'}{\ln(S)}$$

Where:
E : Pielou's Evenness Index
H' : Diversity Index
S : Number of species

The criteria for species evenness according to Pielou (1977): 0.00-0.25: uneven; 0.26-0.50: less evenly distributed; 0.51-0.75: fairly evenly distributed; 0.76-0.95: almost evenly distributed; 0.96-1.00: evenly distributed

Species Richness Index (Dmg)

Margalef Species Richness Index as stated in Odum (1971):

$$\text{Dmg} = \frac{S-1}{\ln(N)}$$

Where:

Dmg : Species Richness Index
S : Number of species
N : Number of individuals for all species

Criteria for species richness values: D<2.5: low species richness; 2.5>D<4: medium species richness; D>4: high species richness

RESULTS AND DISCUSSION

Reef fish species found

Based on the research conducted on five beaches, namely Pringjono Beach, Torohudan Beach, Ngrawah Beach, Dadap Ayam Beach, and Ngrenehan Beach in Gunungkidul (Figure 2), 45 fish species were obtained from 28 families, 1,378 individuals (Table 1). Each fish species has a different number of individuals. The diversity of fish on each beach is also reflected in the number of individuals found (Blowes et al. 2020). Pringjono Beach showed the highest number, with 369 fish individuals recorded, followed by Torohudan Beach, with 321individuals. Dadap Ayam had 297 fish individuals, while Ngrenehan Beach and Ngrawah Beach had lower numbers of individuals, totaling 228 and 163 individuals, respectively. The number of individuals found in Ngrawah Beach was less than the other four beaches. It is because, there were tidal waves and storms at the time of data collection, so researchers had difficulty identifying fish species in the intertidal zone at Ngrawah Beach.

These results illustrate that variations in fish diversity on each beach can be influenced by several factors, including habitat type, environmental conditions, and interactions between species (López-Delgado et al. 2020). If we observed the variety of fish species on each beach, some were only found on one or two specific beaches, while others had a wider distribution across the beaches studied. For example, species such as *bleny* (*Salarias ceramensis*) and *seren* (*Cyclocheilichthys apogon*) were found on all beaches, indicating a broad habitat preference. However, species such as *candukan* fish (*Naso unicornis*) were only found at Torohudan Beach, while *Pelus/ ikan sidat (Anguilla marmorata)* were only found at Torohudan Beach.

Fishes of the family Gobiidae were found in all five beaches studied, especially *Asterropteryx semipunctata* and *Bathygobius fuscus.* These two fish species from the Gobiidae family dominated most stations based on the Shannon Diversity Index and Evenness Index. Fish with this family are also often called amphibious fish. Based on research conducted by Sukiya and Putri (2015), amphibious fish are found on three beaches in Kanigoro Village, Saptosari Sub-district, Gunungkidul. This type of fish can move from one tidepool to another by launching itself. This fish is also quite difficult to catch because it is more often on the bottom of the sand or coral. The fish with the Gobiidae family are preserved from the year of research, 2015. This is because this fish is still easily found on the five beaches studied.

Of the 28 families found, 19 families only have one species. These include Anguillidae, Atherinidae, Balistidae, Caesionidae, Gourami, Hemiscylliidae, Latidae, Leiognathidae, Lutjanidae, Muraenesocidae, Muraenidae, Plotosidae, Scorpanideae, Serranidae, Stromateidae, Synodontidae, Terapontidae, Tetraodontiformes, and Tetrarogidae. Of the 19 species, Anguillidae is the family with the fewest individuals found. The species found in this family is *Anguilla marmorata* which has the local name *pelus* fish or eel fish. Eels are fish that can live in brackish water and also seawater. Eels usually emerge at night, while data collection is carried out in the morning and afternoon, which is why these fish are difficult to find. According to Muthmainnah et al. (2020), eel fish prefer habitats that are not too dense and where activities are not busy. Station 4, or Dadap Ayam Beach, is the station with the least amount of human activity. It is also supported by research conducted by Shuai et al. (2024), which states that eel fish habitat is better far from settlements and with minimal human activity. Eels are also increasingly difficult to find because eels have experienced overfishing or uncontrolled fishing (Barua et al. 2023).

Morphological characteristics

Fish species found in the five research locations have different characteristics. Based on Figure 3, fish species that have unique characteristics are *Echidna nebulosa* with a shape of about 19 to 20 cm long, body width ranging from 1 cm to 2 cm, and black with gray lines. Fish species with attractive and striking colors are *Chrysiptera unimaculata* in yellow and blue, *Abudefduf vaigiensis* in yellow and black, and *Thalassoma lunare* in green and orange. The *A. semipunctata* (*glodog*) fish has a gray color that resembles coral, so *glodog* fish is difficult to catch (Figure 3). Each fish species found has morphometric characteristics such as different lengths and widths. Differences in morphometric characteristics can be caused by age, sex, and environmental factors such as water pH, temperature, salinity, and food (Noor et al. 2021). Another unique species, Lutjanus mahogoni, serves as a vital predator in coral reefs, regulating the populations of small fish and invertebrates. Its reddish-brown body with darker fins makes it a striking and easily identifiable sight in the coral reefs. Pampus argenteus, with its fascinating body shape and flat body, is a compelling subject in coastal and estuarine waters. The E. nebulosa, with its intriguing patterns, plays a significant role in coral reefs, particularly in maintaining cleanliness and ecosystem balance, a contribution that deserves our appreciation (Wilbert and Nugrahapraja 2023). The vibrant colors of these fish, a result of evolution, allow them to blend seamlessly into the colorful coral reefs, which display a wide array of colors and patterns, thereby protecting them from predators and aiding in hunting for prey (Miller and Pawlik 2013).

Number of species

In each research location, there is a comparison of fish diversity spread across each beach. Based on Table 1, Totohudan Beach (Station 4) had the highest number of fish species, with 40 species recorded. It shows significant diversity. Meanwhile, Dadap Ayam Beach (Station 5) and Pringjono Beach (Station 1) also had fairly high numbers of species, with 36 and 33 fish species, respectively. Meanwhile, Ngrenehan Beach (Station 2) and Ngrawah Beach (Station 3) had lower diversity, with only 27 fish species recorded, respectively. If we observed the variety of fish species on each beach, some were only found on one or two specific beaches, while others had a wider distribution across the beaches studied. For example, species such as *S. ceramensis* (*bleny*) and *C. apogon* (*seren*) were found on all beaches, indicating a broad habitat preference. However, species such as *N. unicornis* (*candukan* fish) were only found at Torohudan Beach, while *T. crocodilus* (*ancang ancang*) were only found at Dadap Ayam Beach. These differences in distribution could be due to various factors such as water temperature, salinity, and food availability. First, there are differences in weather at the time of data collection and samples at each station. The weather at the time of data collection and sampling at Station 1 was cloudy, and the waves were calm. Unlike Station 1, at the time of data collection and samples at Station 4, the weather was terrible, characterized by rainstorms and high tides. Storms, hurricanes, and droughts have the potential to wipe out large numbers of intertidal creatures and upset the delicate balance of coastal ecosystems (Santojanni et al. 2023).

The diversity of fish on each beach is also reflected in the number of individuals found (Blowes et al. 2020). Based on the research, the number of individuals found in Ngrawah Beach was less than the other four beaches. It is because, at the time of data collection, there were tidal waves and storms, so researchers had difficulty identifying fish species in the intertidal zone at Ngrawah Beach. These results illustrate that several factors, including habitat type, environmental conditions, and interactions between species, can influence variations in fish diversity on each beach (López-Delgado 2020).

Conservation status

The International Union for Conservation of Nature (IUCN) uses the Red List categories to classify the degree of risk of extinction of a species. Least Concern (LC) conservation Status indicates the least threatened species, and there are 36 fish species at the research site that have LC conservation status. The fish identified in the LC category have a low extinction rate (Miqueleiz et al. 2020; Putra et al. 2022). Thus, the fish is still considered to have a stable population and is not significantly threatened. NT (Near Threatened) conservation status is a conservation status given to species that are believed to be threatened in the future if there are no management efforts against the species (Prakash 2020). One species of fish has a conservation status of Near Threatened (NT), namely *bayeman* fish *(T. lunare)*. With this conservation status, the existence of *bayeman* fish can be threatened in the future if there is no proper management of this fish's existence. There are 2 species included in the Vulnerable (VU) category, namely *L. mahogoni and P. argenteus*. VU is given to species that are proven to meet the criteria in the IUCN that indicate a higher level of risk, namely the reduction in population size in fewer than 10 years, and the species will certainly face extinction in nature (Wijayanti et al. 2018). The population reduction can be caused by the use and exploitation of large-scale, especially in the meat of the fish *L. mahogoni*. NE (Not Evaluated) category means that IUCN has not evaluated its conservation status.Fish included in the NE category are 6, namely *A. semipunctata, Chiloscyllium punctatum, Leiognathus equulus, A. vaigiensis, Diodon histrix*, and *Vespicula depressifrons*. It highlights the importance of continuously monitoring and assessing species populations for conservation and environmental sustainability.

Diversity index

The Diversity Index is a metric used to measure the level of biodiversity within an ecosystem or biological community (Gatti et al. 2020). It encompasses various aspects of biodiversity, including the number of different species and their relative distribution within an area. The results from the five locations listed in Table 2 consistently indicate a high category. All these values fall within the high category of species diversity. It suggests that the ecosystems at all these locations harbor significant biodiversity. Factors influencing this diversity may include diverse habitats, stable environmental conditions, and varied interspecies interactions. For instance, Pringjono Beach, renowned for its marine biodiversity, may exhibit high diversity due to favorable conditions supporting various marine organisms. High biodiversity in an ecosystem can provide better ecological stability and enhance overall ecosystem productivity (Pennekamp et al. 2018). Similarly, it indicates that ecosystems with high species diversity tend to be more resilient to environmental changes and have better regenerative capabilities.

Evenness index

According to Masladen and Sitogasa (2024), Evenness Index is a method used to measure the uniformity of a species' abundance distribution in a community. From the calculations that have been done, it is found that the five stations have index values close to 1, which means the distribution in the community can be said to be evenly distributed with details of the first station of 0.96, station 2 of 0.89 , station 3 of 0.92, station 4 of 0.83, and station 5 of 0.84 (Table 3). Of the five stations, the largest is the 2rd station, namely Ngrenehan Beach. The five stations can be said to be in uniformity, a state that can be attributed to several factors. One of the key contributors is the stability of environmental conditions. This stability provides a reliable backdrop for the species, ensuring they do not face undue pressure that could lead to the dominance of certain species. The availability of sufficient resources further supports this stability, fostering a harmonious and balanced ecosystem where there is no struggle for resources among the existing fish species (Nuranggitasari and Kurniawan 2021). Moreover, the similarity in environmental conditions across the five beaches is a significant factor in this uniformity. The uniformity in substrate type, temperature, and pollution levels suggests a high likelihood of a similar species community (Warahmah et al. 2022).

Species richness index

The species 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 (Roswell et al. 2021). The value of the fish species richness index at the research location is said to be high, that is if the value of the species richness index obtained is greater than 4. The details of the first station of 5.414, station 2 of 4.789 , station 3 of 5.104, station 4 of 6.757 , and station 5 of 6.147 (Table 4) indicate the richness of the fish species at the research location is a high category. So, the results of calculating the species richness index in all research sites have the same category, which has a high fish species richness index with a value above 4.

The five stations have the same species richness index due to their close location, so the adaptation of fish species living is relatively the same between stations. Several factors affect the richness of a species in an ecosystem, including adaptability and habitat (Carminatto et al. 2020). The results of the calculation of the species richness index showed that fish species in the five beaches or stations are classified as numerous. It is supported by Rahmawaty's (2018) statement that the more species and individuals in a place, the higher the value of the species richness Index.

Table 1. Diversity of fish species found in the south coast of Gunungkidul District, Yogyakarta, Indonesia.

Species	Local name	Family	IUCN status	Station 1	2	3	4	5
Abudefduf abdominalis (Quoy & Gaimard, 1825)	*Sersan mayor*	Pomacentridae	LC	20	12	4	16	10
Abudefduf bengalensis (Bloch, 1787)	*Tibok*	Pomacentridae	LC	20	13	8	20	15
Abudefduf septemfasciatus (Cuvier, 1830)	*Asan*	Pomacentridae	LC	22	8	7	20	13
Abudefduf sexfasciatus (Lacepède, 1801)	*Betok Belang*	Pomacentridae	LC	19	10	4	19	17
Abudefduf sordidus (Forsskål, 1775)	*Ikan Asan*	Pomacentridae	LC	26	14	8	6	10
Abudefduf vaigiensis (Quoy & Gaimard, 1825)	*Asan*	Pomacentridae	NE	23	11	6	18	12
Acanthurus lineatus (Linnaeus, 1758)	*Botana*	Acanthuridae	LC	2	-	-	2	-
Aluterus monoceros (Linnaeus, 1758)	*Pogot*	Balistidae	LC	-	-	3	2	6
Anguilla marmorata (Quoy & Gaimard, 1824)	*Pelus/ ikan sidat*	Anguillidae	LC	-	-	-	**1**	-
Asterropteryx semipunctata (Rüppell, 1830)	*Glodok*	Gobiidae	NE	20	29	17	25	19
Atherinomorus duodecimalis (Valenciennes, 1835)	*Merek/ Lumbungan*	Atherinidae	LC	8	2	4	6	9
Bathygobius fuscus (Rüppell, 1830)	*Gobi*	Gobiidae	LC	21	14	8	20	14
Strongylura incisa (Valenciennes, 1846)	*Panju*	Belonidae	LC	-	-	-	1	2
Caesio teres (Seale, 1906)	*Lolosi*	Caesionidae	LC	-	3	12	8	-
Carangoides ferdau (Forsskål, 1775)	*Kwee*	Carangidae	LC	5	2	2	5	10
Caranx sexfasciatus (Quoy & Gaimard, 1825)	*Pungguk/kuwe*	Carangidae	LC	23	10	-	14	-
Chiloscyllium punctatum Müller & Henle, 1838	*Buto nogo*	Hemiscylliidae	NE	-	-	4	8	11
Chrysiptera unimaculata (Cuvier, 1830)	*Mayor*	Pomacentridae	LC	-	-	12	4	-
Congresox talabon (Cuvier, 1829)	*Tanong*	Muraenesocidae	LC	5	3	-	-	7
Cyclocheilichthys apogon (Valenciennes, 1842)	*Seren*	Cyprinidae	LC	19	14	7	4	20
Diodon histrix (Linnaeus, 1758)	*Landak an*	Tetraodontiformes	NE	-	3	1	-	-
Echidna nebulosa (Ahl, 1789)	*Belut Moray Kembang*	Muraenidae	LC	2	-	-	1	3
Epinephelus malabaricus (Bloch & Schneider, 1801)	*Kerapu*	Serranidae	LC	5	2	1	2	4
Euristhmus microceps (Richardson, 1845)	*Sembilang*	Plotosidae	LC	-	5	1	2	1
Glossogobius giuris (Hamilton, 1822)	*Buso/Bloso*	Gobiidae	LC	1	-	-	2	2
Halichoeres chloropterus (Bloch, 1791)	*Keling Hijau*	Labridae	LC	15	4	-	7	11
Labroides dimidiatus (Valenciennes, 1839)	*Dokter*	Labridae	LC	4	2	-	5	4
Lates calcalifer (Bloch, 1790)	*Kakap putih*	Latidae	LC	-	-	4	8	1
Leiognathus equulus (Forsskål, 1775)	*Petek*	Leiognathidae	NE	11	4	2	9	16
Lutjanus campechanus (Poey, 1860)	*Kakap merah*	Lutjanidae	LC	1	-	-	-	1
Lutjanus mahogoni (Cuvier, 1828)	*Ngangas*	Lutjanidae	VU	10	15	8	2	8
Lutjanus malabaricus (Bloch & Schneider, 1801)	*Bangbangan*	Lutjanidae	LC	3	1	-	4	7
Megalaspis cordyla (Linnaeus, 1758)	*Caru*	Carangidae	LC	14	-	7	18	-
Naso unicornis (Forsskål, 1775)	*Candukan*	Acanthuridae	LC	-	-	-	5	-
Pampus argenteus (Euphrasen, 1788)	*Taking*	Stromateidae	VU	8	4	2	-	1
Pterois volitans (Linnaeus, 1758)	*Blarakan*	Scorpanideae	LC	2	-	-	1	-
Rasbora borapatensis (Smith, 1934)	*Wader Kupu*	Cyprinidae	LC	-	15	4	11	7
Salarias ceramensis (Bleeker, 1853)	*Bleny*	Blennidae	LC	20	17	21	8	11
Sphyraena obtusata (Cuvier, 1829)	*Ikan Ancang ancang*	Sphyraenidae	LC	2	-	4	-	1
Syinodus variegatus (Lacepede, 1803)	*Tekekan*	Synodontidae	LC	2	-	-	6	4
Terapon jarbua (Forsskål, 1775)	*Kerong*	Terapontidae	LC	4	-	-	3	4
Thalassoma lunare (Linnaeus, 1758)	*Bayeman*	Labridae	NT	9	-	-	4	7
Trichopsis vitatta (Cuvier, 1831)	*Lero*	Gourami	LC	12	6	-	13	7
Tylosurus crocodilus (Péron & Lesueur, 1821)	*Ancang Ancang*	Belonidae	LC	-	-	-	3	8
Vespicula depressifrons (Richardson, 1848)	*Ipuh*	Tetrarogidae	NE	11	5	2	8	14
			Total	369	228	163	321	297

Note: LC: Least Concern, NT: Near Threatened, VU: Vulnerable, NE: Not Evaluated. Station 1: Pringjono Beach, 2: Ngrenehan Beach, 3: Ngrawah Beach, 4: Torohudan Beach, 5: Dadap Ayam Beach.

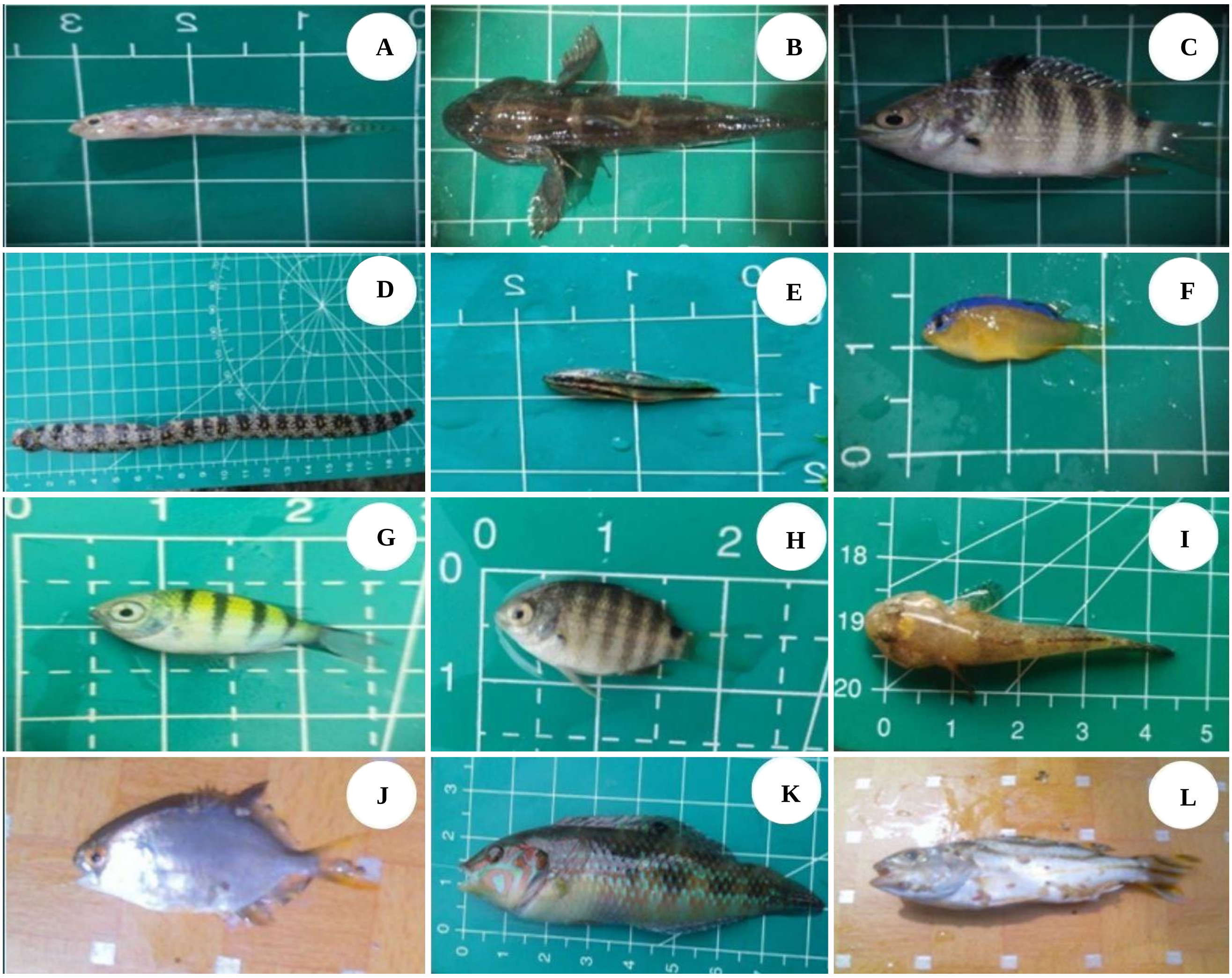

Figure 3. Several types of fish are found in the south coast of Gunungkidul District, Yogyakarta, Indonesia, i.e., Pringjono Beach, Torohudan Beach, Ngrawah Beach, Dadap Ayam Beach, and Ngrenehan Beach: A. *Thalassoma lunare*; B. *Bathygobius fuscus*; C. *Abudefduf abdominalis*; D. *Echidna nebulosa*; E. *Trichopsis vitatta*; F. *Chrysiptera unimaculata*; G. *Abudefduf sordidus*; H. *Abudefduf sexfasciatus*; I. *Glossogobius giuris*; J. *Leiognathus equulus*; K. *Halichoeres chloropterus*; L. *Terapon jarbua*

Table 2. Diversity index of fish in the south coast of Gunungkidul District, Yogyakarta, Indonesia

Stations	Diversity Index (H')	Category
Pringjono Beach	3.365	High
Ngrenehan Beach	2.920	High
Ngrawah Beach	3.023	High
Torohudan Beach	3.028	High
Dadap Ayam Beach	3.091	High

Table 3. Evenness index of fish on the south coast of Gunungkidul District, Yogyakarta, Indonesia

Stations	Evenness index	Category
Pringjono Beach	0.96	Evenly distributed
Ngrenehan Beach	0.89	Evenly distributed
Ngrawah Beach	0.92	Almost evenly distributed
Torohudan Beach	0.83	almost evenly distributed
Dadap Ayam Beach	0.84	almost evenly distributed

Table 4. Species richness index of fish in the south coast of Gunungkidul District, Yogyakarta, Indonesia

Stations	Species richness index	Category
Pringjono Beach	5.414	High
Ngrenehan Beach	4.789	High
Ngrawah Beach	5.104	High
Torohudan Beach	6.757	High
Dadap Ayam Beach	6.147	High

Table 5. Measurement of abiotic factor in the south coast of Gunungkidul District, Yogyakarta, Indonesia

Parameters	Station				
	1	2	3	4	5
Salinity (mg/100g)	3.2	3.2	3.2	3.2	-
pH of water	6.98	8.55	8.26	8.38	7.92
Water temperature (°C)	30.8	30.3	30.3	30.1	29.9
DO (mg/L)	0.7	0.30	0.49	1.7	2.31

Note: Station 1: Pringjono Beach, 2: Ngrenehan Beach, 3: Ngrawah Beach, 4: Torohudan Beach, 5: Dadap Ayam Beach

Abiotic factor

Abiotic factors measured at each research point include salinity, pH, water temperature, and DO (Table 5). As a result, 4 out of 5 Stations have similarities in salinity parameters and slight variations in water temperature. While the salinity of the surrounding ocean influences beach salinity, most beaches have similar salinity levels. The breakdown of salts from the Earth's crust and weathering of rocks are the main sources of salt in the oceans. Evaporation from the ocean surface also contributes to overall salinity. The evaporation factor of seawater also plays a role in salinity because as seawater evaporates, the remaining water becomes more concentrated with salt, maintaining the average salinity level (Geng et al. 2016). Naturally, coasts closer to the equator will be warmer throughout the year than those further away. The climate also affects temperature; it's important to note that weather patterns always differ depending on the season and location, contributing to the dynamic nature of temperature variations (Lusiani and Wally 2020).

For the pH parameter, there are more variations in differences from the range of 6.98-8.55. Fluctuations in O2 and CO2 content can cause the difference in pH levels between beaches (Rukminasari et al. 2014). In addition, the difference in the results obtained can also be caused by the time of collection. The collection of abiotic data at each beach is conducted during low tide. The times of high and low tides can change every day. Therefore, there are differences in the timing of abiotic factor data collection. The range of differences in DO levels from each station also varies, ranging from 0.30-2.31. Dissolved oxygen concentrations tend to be higher in areas close to land and at sea level for each tidal height condition (Cravo et al. 2020; Madyawan et al. 2020).

In conclusion, the study identified 1,378 individuals comprising 45 species and 28 families. The highest number of individuals was caught at Pringjono Beach, with 369 individuals. The *A. semipunctata* and *B. fuscus* from the Gobiidae family dominated at the majority of stations. The Diversity Index (H') indicated high species diversity across all stations, with the highest value of 3.562 and the lowest of 3.023. For the Evenness Index, the majority of the five stations were classified as almost evenly distributed, with the lowest value being 0.92 and the highest being 0.97. Meanwhile, the high richness index of the fish species at the five research locations underscores the abundance of fish species in these areas. There are some differences in abiotic factors in sampling stations. Salinity, water pH, water temperature, and DO can affect the composition and distribution of reef fish in the littoral zone in Gunungkidul.

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