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Investigating Fish Composition and Diversity About Physicochemical Oceanographic Conditions Captured in the Cape Region, Bone Gulf, South Sulawesi, Indonesia

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ABSTRACT

Coastal areas, especially around headlands, are crucial for maintaining biodiversity in coastal ecosystems. However, environmental factors and anthropogenic pressures can threaten their sustainability. This study aimed to analyze the influence of variations in environmental factors on the most abundant fish species in coastal headlands, as well as the impact of seasonal changes on the composition, structure, and diversity of fish communities in Bone District, South Sulawesi. Fish catch data were collected at three fishing stations using passive traps (sero) four times a month from February to November 2023. Environmental conditions, including temperature, current speed, pH, salinity, dissolved oxygen (DO), turbidity, and phosphate, were measured. The results revealed that 69 fish species from 42 families were found, with a total of 2,059 individuals. Fish diversity was higher at stations II (diversity index 3.17) and III (3.32) compared to station I (2.6). Environmental factors affecting fish abundance included DO, current speed, pH, and salinity. Most fish species were categorized as Least Concern (LC) according to the IUCN. The sustainability of coastal habitats is essential for maintaining species diversity, with ongoing management recommendations that consider climate change, pollution, and human impacts. Further research is needed to monitor changes in seasonality and habitat quality.

INTRODUCTION

The cape area is mountainous, with rocky, sandy, and seagrass substrates parallel to the coastline, typically in shallow waters **(Magill, 1989)**. Seawater tides, river discharges, waves, and coastal current patterns affect physical variables and coastal ecosystems. Meteorological factors, like wind and precipitation, can influence the dynamics of these ecosystems **(Wang *et al.*, 2022)**. Shallow and marginal vegetated and non-vegetated zones (e.g., beaches and tidal flats) around river mouths and coastal lagoons are critically significant habitats, particularly for the juvenile stages of fish and invertebrates **(Lin *et al.*, 2020)**. These habitats are characterized by submerged vegetation (e.g., *Ruppia* *maritima* and *Spartina alterniflora*) and hold biological importance for the juvenile stages of fish species, including those of economic relevance. Keystone species, including trees, corals, and seagrasses, are essential to global ecosystem functions and services **(Angelini *et al.*, 2011)**, especially by facilitating habitat formation. This area is near a mountain filled with rooted trees up to the edge of the beach. Moreover, it has also seagrass beds that serve as a search place for fish with a high economic value **(Blandon & Ermgassen, 2014; Laís *et al.*, 2020; Jones *et al.*, 2021; Eggertsen *et al.*, 2022)**. It provides food, food chains, biodiversity, and ecosystem services that support the productivity of coastal waters **(Greening & Janicki, 2006; Cucio *et al.*, 2016)**. Biodiversity shows the diversity of animals, plants, microbes, genetic composition, and the environment they create **(Swingland, 2013)**. Moreover, biodiversity makes a variety of important contributions to life on Earth. Each species has a unique role in the ecosystem, such as protecting freshwater resources, providing food, maintaining ecological stability, controlling pollution, preventing soil erosion and flooding, and supporting climate stability **(Sahney *et al.*, 2010; Musbir & Bohari, 2021)**.

Therefore, biodiversity loss, especially habitat biodiversity, and ecosystem homogenization are global threats **(Kano *et al.*, 2016)**. In addition to artisanal fishing activities, which are not intensively managed and still use traditional trap nets, fishing was carried out near the rocky headlands for this study. Traditional trap nets are the main artisanal fishing tools used to catch fish in coastal areas and are known to produce very large bycatch against the juveniles of several species of fish **(Musbir *et al.*, 2021; Patangngari & Musbir, 2024)**.

The peripheral shallow parts of coastal lagoons, acting as a transition zone between terrestrial and marine habitats and in areas significantly affected by human activities, such as agriculture, tourism, industry, and urbanization, they endure substantial anthropogenic stress **(Silva et *al.*, 2024)**. The physical dynamics of shallow marginal zones in lagoons and coastal estuaries generate varied habitats for several species during their life cycles, including feeding regions, nurseries, reproductive sites, shelters, and growing areas **(Shen *et al.*, 2015; Rhodes *et al.*, 2017)**. However, daily and seasonal environmental dynamics greatly influence species' use, distribution, and abundance in a habitat location **(Singha Roy *et al.*, 2018; Min & Kim, 2023)**. The primary emphasis of the study conducted by several groups is the biological interactions in coastal lagoons **(Fortes *et al.*, 2014)**. This knowledge is very important to improve the management of the coastal environment. Maintaining the biological diversity or capability of population structures can build and ensure resilience to climate change **(Patangngari *et al.*, 2022a)**.

This study examined the concept that annual fluctuations in the composition and diversity of fish stocks in the shallow marginal shore of Bone Regency are affected by environmental conditions, highlighting the importance of this subject and the lack of research on Bone waters. To clarify the proposed hypothesis, the following objectives were analyzed: (i) the influence of environmental fluctuations on the dominant species within fish populations and (ii) the impact of seasonal changes on environmental characteristics and the composition, structure, and diversity of fish populations.

MATERIALS AND METHODS

Study area

The sample collection site is located along the coast of Tanjung Pallette and Tanjung Cempalagi, which are rocky hills in Bone Regency. These hills are directly adjacent to the coast and are flanked by three small rivers: the Pallette River, Mallari River, and Bulu River. The rivers are long enough to carry relatively abundant freshwater, especially during the rainy season. The fishing gear is set up near the rocky headlands, which are situated on sand and seagrass beds, with a depth of 1.5 to 2 meters when installed. This area is very productive because, in addition to being used as a small-scale fishing area **(Surachmat *et al.*, 2017; Patangngari *et al.*, 2022)** and as a seaweed cultivation area **(Hardiana *et al.*, 2024)**, which is home to marine organisms.

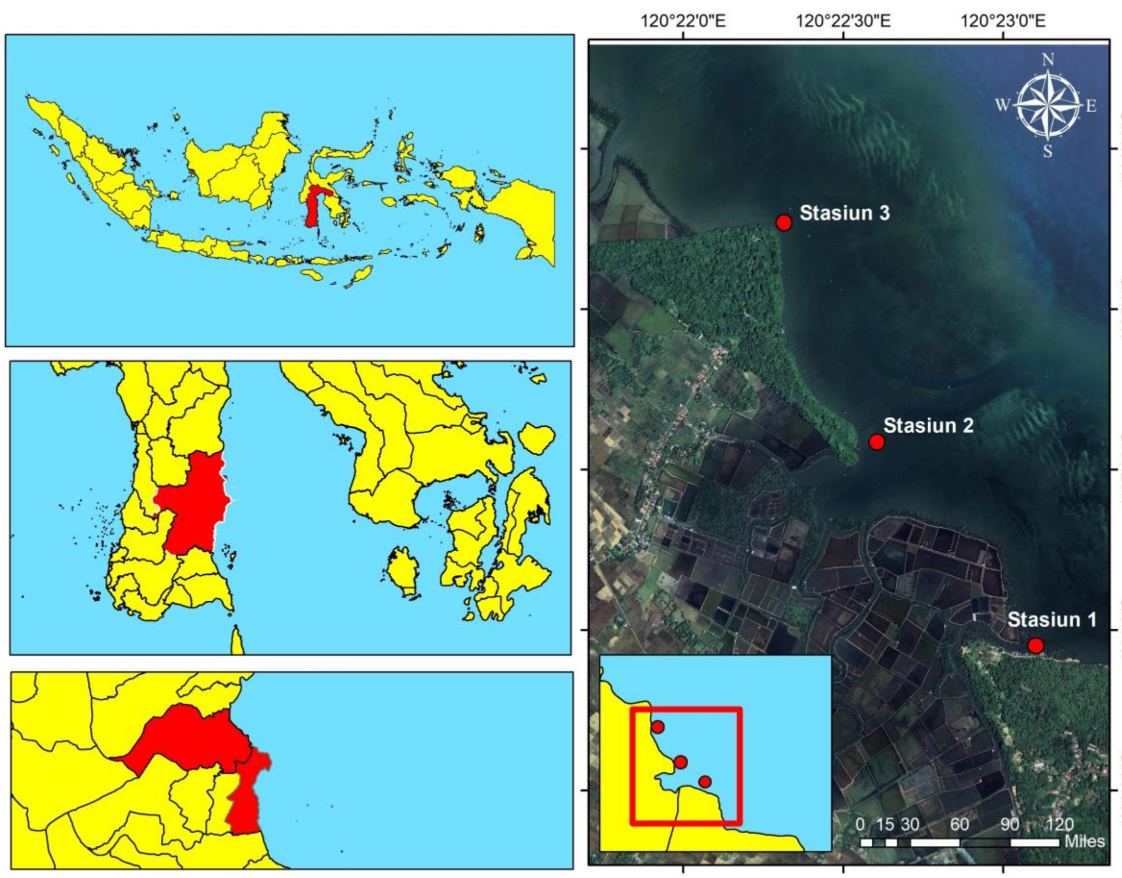


Fig. 1. Research location map

Data collection

Catch data were collected from February to August on the coast of Tanjung Pallette and Cempalagi, Bone Gulf, Bone Regency, South Sulawesi, Indonesia. In this study, fish catch data were collected from three different stations in the waters of Bone Gulf. The data collection process involved recording the number of fishes caught four times to assess fish abundance, species diversity, and the total length of the fish. The caught fish were then sorted into species groups for identification. Fish identification followed the methods outlined by **Saanin (1995)** and **Carpenter and Niem (2001)**. The species' conservation status was determined using fish databases and SealifBase, as well as the International Union for Conservation of Nature (IUCN) Red List for both fish and non-fish species.

Sampling method

The sampling method used was a passive trap (*sero*) with an appropriate mesh size to avoid size errors in fishing. Sampling was carried out monthly for ten months to capture species variation under different ecological conditions on the fish diversity index. The fish caught were separated into species groups for identification. In addition, environmental conditions were also measured *in situ*, which was carried out twice monthly to determine the conditions of fluctuations in environmental or seasonal dimensions at the research site. The environmental parameters measured were temperature, current speed, DO (Dissolved oxygen), pH, salinity, transparency, nitrate, turbidity, and phosphate.

Table 1. Sampling sites at the Bone Gulf

Sampling point	Latitude	Longitude
ST1	4°28'4.44"S	120°23'24.63"E
ST2	4°27'20.32"S	120°22'37.17"E
ST3	4°26'48.69"S	120°22'23.72"E

Data analysis

The diversity index (H’) was periodically calculated by modifying the number of collected samples to accurately represent the real catch by fishermen. It was determined by multiplying the number of fishes in the sample by the total weight of the catch and dividing by the sample weight. The diversity index (H’) was calculated using the methods proposed by **Shannon and Weaver (1949)** as follows:

$$H' = SUM\ [Pi\ \times \log\ (Pi)]$$

Where, pi = ni/N; ni = number of individuals of each species in the sample; and N = total number of individuals of all species in the sample.

Evenness (E) was used to describe the similarity of abundance of different species in a community:

$$E = \frac{H'}{LnS}$$

In this context, E represents the evenness index; H’ denotes Shannon's diversity index; and ln S signifies the natural logarithm of the total number of unique species.

RESULTS AND DISCUSSION

Fish species found in the rocky headland coastal area

From February to August, catch data were collected in the rocky headland areas of Tanjung Pallette and Cempalagi over a period of seven months. This area was equipped with static fishing gear in the form of traps. Three research stations were selected through purposive sampling. The number of individuals collected at each station was as follows: Station 1 (ST 1) had 432 individuals, with 34 species from 24 families; Station 2 (ST 2) had 1,046 individuals, with 44 species from 32 families; and Station 3 (ST 3) had 581 individuals, with 31 species from 23 families. Overall, the total catch from the three stations consisted of 2,059 individuals, 69 species, and 42 families (Table 2).

The five most abundant families and their species include:

1. **Siganidae**:
   - White-spotted spinefoot (*Siganus canaliculatus* Park, 1797)
   - Orange-spotted spinefoot (*S. guttatus* Bloch, 1787)
   - Streaked spinefoot (*S. javus* Linnaeus, 1758)
   - Little spinefoot (*S. spinus* Linnaeus, 1758)
   - Vermiculated spinefoot (*S. vermiculatus* Valenciennes, 1835)
2. **Lutjanidae**:
   - Blackspot snapper (*Lutjanus ehrenbergii* Peters, 1869)
   - Dory snapper (*L. fulviflamma* Forsskål, 1775)
   - Blubberlip snapper (*L. rivulatus* Cuvier, 1828)
   - Yellowfin snapper (*L. xanthopinnis* Iwatsuki, Tanaka & Allen, 2015)
3. **Carangidae**:
   - Indian threadfish (*Alectis indicus* Rüppell, 1830)
   - Bluespotted trevally (*Caranx bucculentus* Alleyne & Macleay, 1877)
   - Tille trevally (*C. tille* Cuvier, 1833)
   - Cocinero (*C. vinctus* Jordan & Gilbert, 1882)
   - Coastal trevally (*Turrum coeruleopinnatum* Rüppell, 1830)
4. **Epinephelinae**:
   - Malabar grouper (*Epinephelus malabaricus* Bloch & Schneider, 1801)
   - Longfin grouper (*E. quoyanus* Valenciennes, 1830)
   - Greasy grouper (*E. tauvina* Fabricius, 1775)

Maintaining fish diversity is essential. One way to ensure its conservation is by conducting scientific reporting and documentation, which will allow for future evaluation and appropriate conservation efforts in coastal areas **(Schmidt *et al.*, 2022; Li *et al.*, 2024)**.

Species composition and IUCN red list status

Four IUCN statuses were successfully determined for the diverse fish species collected: LC (Least Concern), NR (Not Recognized), DD (Data Deficient), and NE (Not

Evaluated). Of the 69 species identified, 51 were classified as LC, 2 as NR, 3 as DD, and 13 as NE.

Three fish species in the LC category include:

- Yellowfin surgeonfish (*Acanthurus xanthopterus* Valenciennes, 1835) at 0.2%
- Indian threadfish (*Alectis indicus* Rüppell, 1830) at 0.8%
- Bluespotted trevally (*Caranx bucculentus* Alleyne & Macleay, 1877) at 4.4%.

Fish with NR status include:

- Spotted sicklefish (*Drepane punctata* Linnaeus, 1758) at 0.2%
- Fourfinger threadfin (*Eleutheronema tetradactylum* Shaw, 1804) at 0.1%.

Fish with DD status consist of:

- Greasy grouper (*Epinephelus tauvina* Fabricius, 1775) at 1.0%
- Indo-Pacific tarpon (*Megalops cyprinoides* Broussonet, 1782) at 1.2%
- Yellowfin snapper (*Lutjanus xanthopinnis* Iwatsuki, Tanaka & Allen, 2015) at 0.5%.

Fish with NE status include:

- Whiteleg shrimp (*Penaeus vannamei* Boone, 1931) at 1.0%
- Banana prawn (*Penaeus merguensis* De Man, 1888) at 0.1%
- Macrophthalmus japonicus (*De Haan*, 1835) at 0.1%
- Reef crab (*Ozius truncatus* Milne-Edwards, 1834) at 0.1%.

Table 2. A collection of fish communities caught in the Cape area

Family/ Scientific name	Common name	ST1	ST2	ST3	F	RA	IUCN
Acanthuridae							
Acanthurus xanthopterus (Valenciennes, 1835)	Yellowfin surgeonfish	-	3	2	5	0.2%	LC
Carangidae							
Alectis indicus (Rüppell, 1830)	Indian threadfish	-	17	-	17	0.8%	LC
Caranx bucculentus (Alleyne & Macleay, 1877)	Bluespotted trevally	9	61	22	92	4.4%	LC
Caranx tille (Cuvier, 1833)	Tille trevally	4	-	2	6	0.3%	LC
Caranx vinctus (Jordan & Gilbert, 1882)	Cocinero	-	9	-	9	0.4%	LC
Ambassidae							
Ambassis vachelli (Richardson, 1846)	Vachelli's glass perchlet	-	9	-	9	0.4%	LC
Loliginidae							
Loligo sp.	Squid	17	-	-	17	0.8%	LC
Tetraodontidae							
Arothron manilensis (Marion de Procé, 1822)	Narrow-lined puffer	3	-	-	3	0.1%	LC
Chelonodon patoca (Hamilton, 1822)	Milkspotted puffer	3	10	-	13	0.6%	LC
Calliurichthys japonicus	Japanese longtail	-	-	2	2	0.1%	LC

(Houttuyun, 1782)	dragonet						
Turrum coeruleopinnatum (Rüppell, 1830)	Coastal trevally	16	144	147	307	14.6%	LC
Chanidae							
Chanos chanos (Fabricius, 1775)	Milkfish	36	133	72	241	11.4%	LC
Ephippidae							
Cherenimungli sheeli (Fabricius, 1775)	Bluespot mullet	-	-	22	22	1.0%	LC
Drepaneidae							
Drepane punctata (Linnaeus, 1758)	Spotted sicklefish	-	4	-	4	0.2%	NR
Polynemidae							
Eleutheronema tetradactylum (Shaw, 1804)	Fourfinger threadfin	-	2	-	2	0.1%	NR
Epinephelinae							
Epinephelus malabaricus (Bloch & Schneider, 1801)	Malabar gropuer	13	-	-	13	0.6%	LC
Epinephelus quoyanus (Valenciennes, 1830)	Longfin grouper	-	2	-	2	0.1%	LC
Epinephelus tauvina (Fabricius, 1775)	Greasy grouper	-	12	10	22	1.0%	DD
Bleiidae							
Eubleekeria jonesi (James, 1971)	Jones' pony fish	16	-	-	16	0.8%	LC
Gerreidae							
Gerres filamentosus (Cuvier, 1829)	Whipfin silver-biddy	-	53	8	61	2.9%	LC
Gobiidae							
Glossogobius giuris (Hamilton, 1822)	Tank goby	-	16	2	18	0.9%	LC
Carangidae							
Gnathanodon speciosus (Forsskål, 1775)	Golden trevally	-	2	-	2	0.1%	LC
Sciaenidae							
Johnius borneensis (Bleeker, 1851)	Sharpnose hammer croaker	-	5	-	5	0.2%	LC
Lobotidae							
Labotes surianmensis (Bloch, 1790)	Tripletail	-	-	2	2	0.1%	LC
Lobotes pacificus (Gilbert, 1898)	Pacific tripletail	-	4	-	4	0.2%	LC
Latidae							
Lates calcarifer (Bloch, 1790)	Barramundi	7	-	-	7	0.3%	LC
Leiognathidae							
Leiognathus equula (Forsskål, 1775)	Common ponyfish	25	24	16	65	3.1%	LC
Lethrinidae							
Lethrinus harak (Fabricius, 1775)	Thumbprint emperor	-	7	-	7	0.3%	LC
Lethrinus lentjan (Lacepède,	Pink ear emperor	5	2	-	7	0.3%	LC

1802)							
Penaeidae							
Penaeus vannamei (Boone, 1931)	Whiteleg shrimp	-	2	-	2	0.1%	NE
Penaeus merguensis (De Man, 1888)	Banana prawn	-	17	-	17	0.8%	NE
Penaeus monodon (Fabricius, 1798)	Giant tiger prawn	-	18	3	21	1.0%	NE
Mullidae							
Moolgarda pederaki (Valenciennes,1836)	Longfin mullet	-	17	29	46	2.2%	NE
Moolgarda perusii (Valenciennes, 1836)	Longfinned mullet	3	-	-	3	0.1%	LC
Lutjanidae							
Lutjanus ehrenbergii (Peters, 1869)	Blackspot snapper	17	-	-	17	0.8%	LC
Lutjanus fulviflamma (Forsskål, 1775)	Dory snapper	-	3	4	7	0.3%	LC
Lutjanus rivulatus (Cuvier, 1828)	Blubberlip snapper	3	3	-	6	0.3%	LC
Lutjanus xanthopinnis (Iwatsuki, Tanaka & Allen, 2015)	Yellowfin snapper	-	-	10	10	0.5%	DD
Macrophthalmidae							
Macrophthalmus japonicus (De Haan, 1835)	Japanese sentinel crab	-	3	-	3	0.1%	NE
Megalopidae							
Megalops cyprinoides (Broussonet, 1782)	Indo-Pacific tarpon	4	19	2	25	1.2%	DD
Mulloidichthyidae							
Mulloidichthys flavolineatus (Lacepède, 1801)	Yellowstripe goatfish	-	-	2	2	0.1%	LC
Oziidae							
Ozius truncatus (Milne-Edwards, 1834)	Reef crab	-	2	-	2	0.1%	NE
Platycephalidae							
Platax orbicularis (Forsskål, 1775)	Orbicular batfish	22	-	-	22	1.0%	LC
Platax pinnatus (Linnaeus, 1758)	Dusky batfish	1	4	-	5	0.2%	NE
Portunidae							
Plototus lineatus (Thunberg, 1787)	Striped eel catfish	-	33	6	39	1.8%	NE
portunnus pelagicus (Linnaeus, 1758)	Blue swimming crab	17	-	12	29	1.4%	NE
Scylla serrata (Forsskal, 1775)	Mud crab	2	19	48	69	3.3%	LC
Carangidae							
Pseudocaranx dentex (Bloch & Schneider, 1801)	White trevally	16	-	-	16	0.8%	LC
Pleuronectidae							
Pseudorhombus javanicus	Javan flounder	-	2	2	4	0.2%	LC

(Bleeker, 1853)							
Scombridae							
Rastrelliger kanagurta (Cuvier, 1816)	Indian mackerel	3	-	-	3	0.1%	LC
Scatophagidae							
Scatophagus argus (Linnaeus, 1766)	Spotted scat	12	-	-	12	0.6%	LC
Scombridae							
Scomberoides lysan (Fabricius, 1775)	Doublespotted queenfish	8	-	-	8	0.4%	LC
Scomberoides tala (Cuvier, 1832)	Barred queenfish	-	22	2	24	1.1%	LC
Siganidae							
Siganus canaliculatus (Park, 1797)	White-spotted spinefoot	32	-	-	32	1.5%	LC
Siganus guttatus (Bloch, 1787)	Orange-spotted spinefoot	29	32	2	63	3.0%	LC
Siganus javus (Linnaeus, 1766)	Streaked spinefoot	-	13	27	40	1.9%	LC
Siganus spinus (Linnaeus, 1758)	Little spinefoot	18	-	-	18	0.9%	LC
Siganus Vermicultus (Valenciennes, 1835)	Vermiculated spinefoot	32	26	18	76	3.6%	LC
Sillaginidae							
Sillago sihama (Fabricius, 1775)	Silver sillago	6	-	-	6	0.3%	LC
Scombroidei							
Sphyraena barracuda (Edwards, 1771)	Great barracuda	3	4	2	9	0.4%	LC
Sphyraena forsteri (Cuvier, 1829)	Bigeye barracuda	19	-	-	19	0.9%	NE
Belonidae							
Strongylura leiura (Bleeker, 1850)	Banded needlefish	-	36	-	36	1.7%	NE
Strongylura strongylura (Van Hasselt, 1823)	Spottail needlefish	-	2	-	2	0.1%	NE
Teraponidae							
Terapon jarboa (Fabricius, 1775)	Jarbua terapon	17	9	8	34	1.6%	LC
Thalamitidae							
Thalamita crenate (Milne-Edwards, 1834)	Wide front swimcrab	5	203	92	300	14.2%	NE
Toxotes jaculatrix							
Toxotes jaculatrix (Pallas, 1767)	Banded archerfish	-	4	-	4	0.2%	LC
Mullidae							
Upeneus sulphureus (Cuvier, 1829)	Sulphur goatfish	-	14	-	14	0.7%	LC
Upeneus vittatus (Forsskål, 1775)	Yellowstriped goatfish	-	18	5	23	1.1%	LC
Mugilidae							
Valamugil buchanani (Bleeker, 1853)	Bluetail mullet	9	-	-	9	0.4%	LC

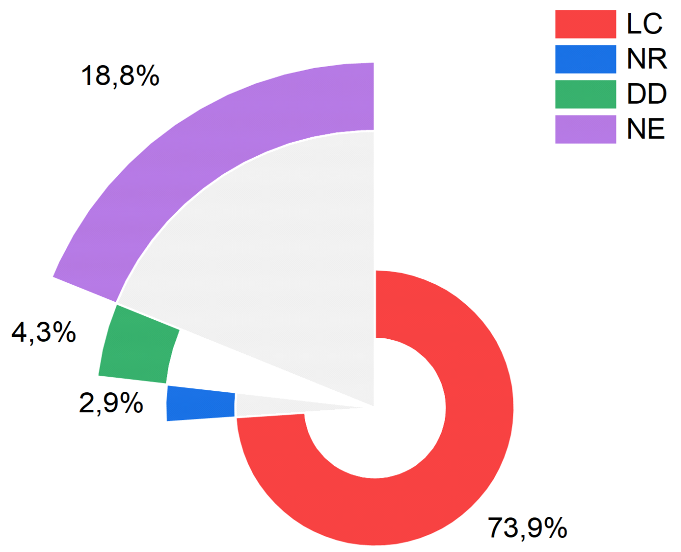


Fig. 2. International Union for Conservation of Nature (IUCN) status (LC= Least Concern; NR (Not Recognized); DD (Data Deficient); NE (Not Evaluated); VU (Vulnerable), EN (Endangered)

Top 6 species of fish caught

The highest catches during data collection were *Turrum coeruleopinnatum (Rüppell, 1830)* with 14.6%, *Thalamita crenate* (Milne-Edwards, 1834) with 14.2%, *Chanos chanos* (Fabricius, 1775) with 11.4%, *Caranx bucculentus* (Alleyne & Macleay, 1877) with 4.4%, *Siganus Vermicultus* (Valenciennes, 1835) with a percentage of 3.6%, and *Scylla serrata* (Forsskal, 1775) with a percentage of 3.3%. Fig. (3) shows a visualization of fish distribution data with the highest percentage of individuals at three stations.

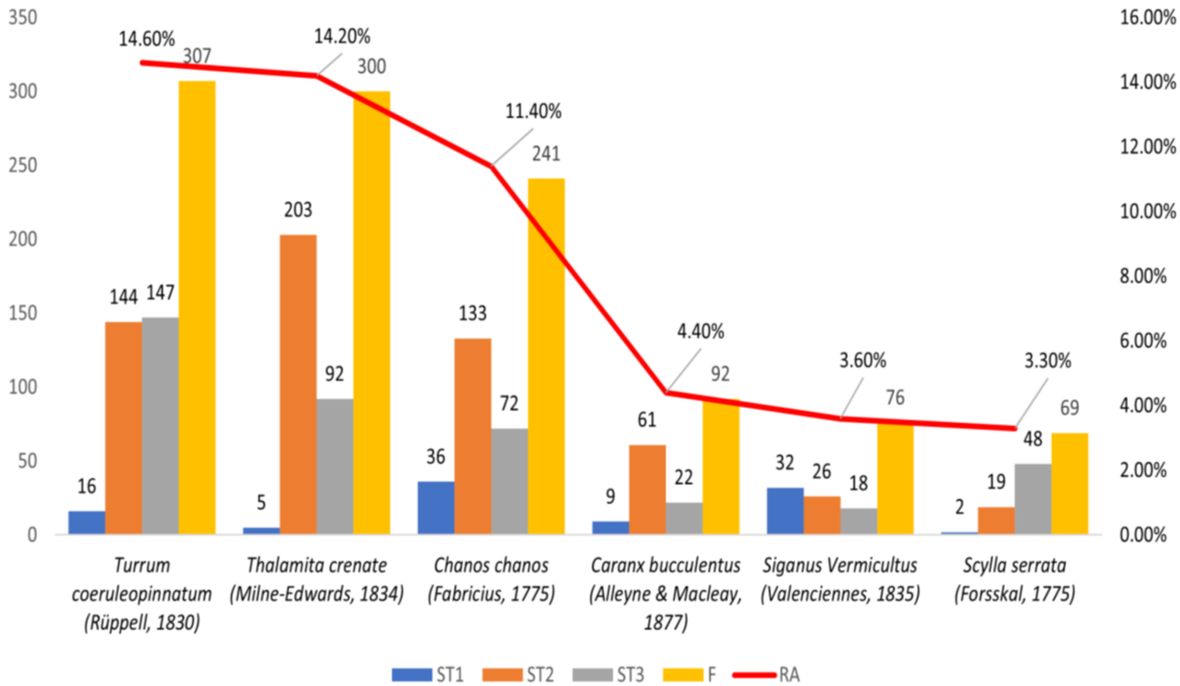


Fig. 3. Top six fish species caught

Diversity, evenness, species richness, and dominance index

The balance of fish community structure and the richness of fish species in aquatic ecosystems can be seen through the index of diversity, equity, and dominance **(McLean *et al.*, 2019)**. The diversity index is a value that can indicate the balance of diversity by dividing the number of individuals of each type **(Fua *et al.*, 2024)**. The results analysis of the diversity, evenness, and dominance indices are presented in Table (5). The Shannon-Wiener diversity index (H') reveals the following values: ST I has a value of 3.32, ST II has 3.17, and ST III has 2.6. According to the index criteria, species diversity at ST II and ST III is considered high, while ST I is categorized as low.

The evenness index (E) for the stations are as follows: ST I is 0.92, ST II is 0.71, and ST III is 0.73. These evenness values suggest that although the populations across the three stations exhibit low evenness, the values near 1 indicate a relatively uniform distribution among species, with nearly equal numbers of individuals per species.

The dominance index (C) shows that ST I has a value of 0.042, ST II is 0.078, and ST III is 0.11. Based on the dominance index criteria ($C < 0.5$), it can be concluded that no species is dominant in any of the stations. Thus, none of the stations are ecosystems dominated by a single species.

The species richness index indicates that ST II has the highest value of 6.90, followed by ST I at 5.68, and ST III at 5.14. This index provides a comprehensive overview of the balance and health of the ecosystems at each research station.

The analysis shows that ST II and ST III have better species diversity and richness than ST I. This information can serve as a basis for sustainable ecosystem management **(Rohim *et al.*, 2024; Tuncharoen *et al.*, 2024)**. To achieve sustainable management, it is important to maintain high diversity, good evenness, and prevent excessive dominance by a few species **(Derebe *et al.*, 2023)**. Data from these three indices can guide fisheries management and aquatic ecosystem conservation policies **(Stirling & Wilsey, 2001)**. Additional details can be found in Table (3) and Fig. (4).

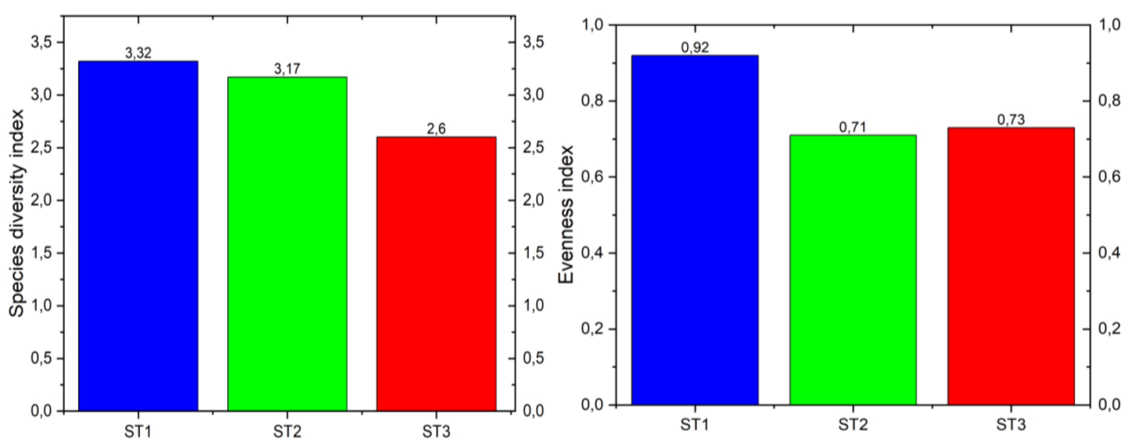
Table 3. Ecological index of the rabbitfish species in two bay locations in Bone Gulf, Bone District, South Sulawesi, Indonesia

Parameter	ST I	ST II	ST III
Species diversity index	3.32	3.17	2.6
Evenness index	0.92	0.71	0.73
Species richness	5.68	6.9	5.14
Dominance index	0.042	0.078	0.11

Relationship of fish assemblage and environmental parameters

The physicochemical parameters of the water measured during the study in the coastal area of Bone Gulf are shown in Table (4). The temperature ranged from 28.94 to 29.20°C, current speed varied between 0.18 and 0.21 m/s, dissolved oxygen (DO) ranged from 6.51 to 6.71mg/ L, and pH levels ranged from 7.73 to 7.93. Salinity levels varied between 28.62 and 30.95ppt, transparency ranged from 0.54 to 0.75 m, nitrate levels were between 0.67 and 0.84mg/ L, turbidity ranged from 0.71 to 2.16 NTU, and phosphate levels ranged from 0.01 to 0.03mg/ L.

In addition, environmental conditions exhibited a wide range of transparency. Areas near the cape had lower transparency due to the influence of river water and the constant wave action on the rocks, which stirred the water. This resulted in very low transparency and high turbidity values compared to seaweed cultivation zones, which exhibited higher transparency and lower turbidity levels. As a result, the water in the seaweed cultivation areas appeared clear and blue **(Hardiana *et al.*, 2024; Zhang *et al.*, 2024)**.



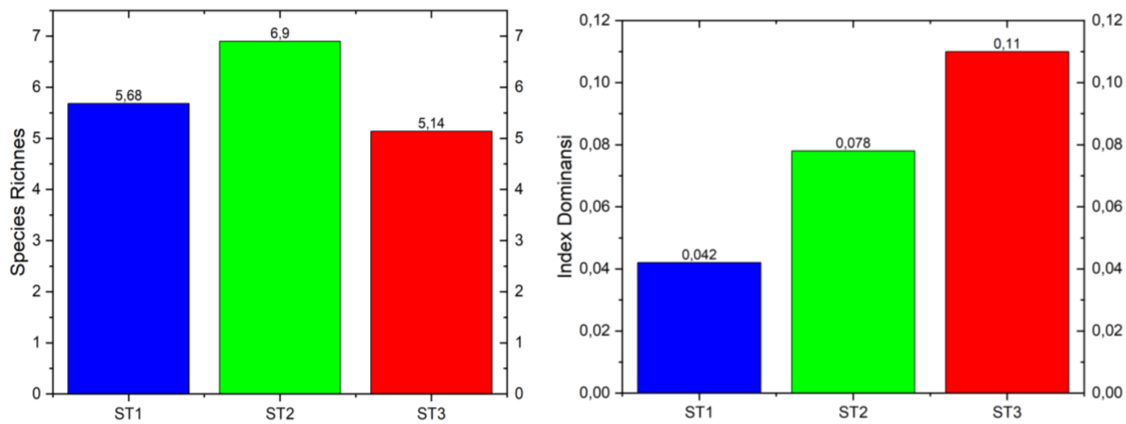


Fig. 4. Diversity, evenness, species richness, and dominance index

Table 4. Ranges of physio-chemical parameters measured at the Bone Gulf, Indonesia

Parameter Oceanography	STI ± STDEV	STII ± STDEV	ST III ± STDEV
Temperature (°C)	28.94±0.54	29.20±0.77	29.17±0.41
Current speed (m/s)	0.21±0.05	0.21±0.05	0.18±0.07
Dissolved oxygen (mg/L)	6.62±0.43	6.71±0.41	6.51±0.22
pH	7.89±0.44	7.93±0.35	7.73±0.23
Salinity (ppt)	29.24±5.68	28.62±4.59	30.95±5.51
Transparency (m)	0.54±0.10	0.68±0.15	0.75±0.19
Nitrate (mg/L)	0.67±0.06	0.76±0.23	0.84±0.11
Turbidity (NTU)	1.22±0.80	2.16±1.35	4.37±1.79
Phosphate (mg/L)	0.03±0.01	0.019±0.0004	0.02±0.004

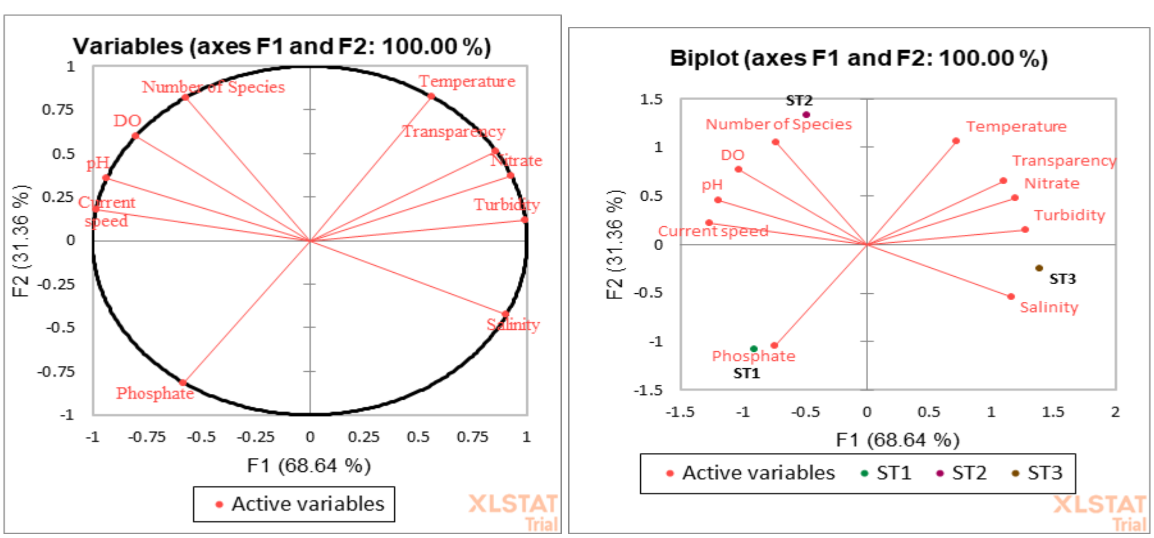


Fig. 5. Biplot graph of PCA analysis: **A.** Environmental factors and number of species, **B.** Environmental factors, fishing trap installation stations at the research site

Understanding the relationship between the physicochemical environment and fish populations is crucial for managing sustainable fisheries. Using principal component analysis (PCA), biplot graphs were generated to explore the correlations between various environmental factors, fish catches, and station characteristics. In PCA, angles less than 90° indicate strong correlations, while angles greater than 90° indicate no correlation. The correlation matrix was obtained using ExcelSTAT, and the results are presented in Fig. (5).

The PCA analysis revealed that the environmental factors and research stations are spread across different quadrants. Each station has distinct characteristics:

- Station I (ST I) is primarily influenced by phosphate levels.
- Station II (ST II) is characterized by dissolved oxygen (DO), pH, and current speed, correlating with the location of fishing traps near large rivers.
- Station III (ST III) is dominated by salinity, linked to its proximity to a small river near the cape.

Interestingly, temperature, transparency, nitrate, and turbidity were not strongly correlated with any of the stations' characteristics.

The most significant factors influencing fish abundance at the research sites include DO, pH, and current velocity. These parameters are located in quadrant one of the PCA biplot, indicating their positive correlation with fish populations. The study site, located between steep mountain slopes, is a unique habitat for various fish species. The area's proximity to both large and small rivers plays a key role in shaping fish distribution.

Phosphate and turbidity were identified as key environmental factors, linked through the eutrophication process. Phosphates serve as nutrients for microorganisms, especially algae. Increased phosphate concentrations can lead to excessive algae growth, which, when decomposed, raises turbidity levels and lowers DO levels in the water—conditions detrimental to aquatic life **(Baustian *et al.*, 2018; Beau & Brischoux, 2021)**. High phosphate levels often result from agricultural runoff, exacerbating water quality issues and further affecting fish populations.

Current speed is a crucial determinant of fishing success in coastal areas, especially near headlands and cliffs. The intensity of ocean currents influences the distribution and foraging behavior of fish. Nutrient-rich waters, driven by fluctuating currents, foster the growth of small fish and plankton, which in turn supports predatory fish populations **(Zhao *et al.*, 2023)**. In coastal areas, moderate currents often enhance fish aggregation and foraging conditions, while excessively strong currents can disrupt fish mobility, reducing fishing efficiency **(Claireaux *et al.*, 2018)**. Steady currents typically increase fish populations and improve fishing outcomes **(Tixier *et al.*, 2018)**. Additionally, the placement of fishing traps in areas with optimal current speeds and proximity to rivers further boosts catch success.

The study also highlighted the influence of DO and pH levels on fish abundance. In areas with low DO (hypoxia), fish are often forced to migrate to regions with higher oxygen levels, or their populations decrease significantly. This can directly affect fishing yields. Habitat quality also plays a vital role in the survival of fish populations, as disturbances can lead to decreased reproductive rates and overall health **(McDonnell *et al.*, 2019)**. pH levels that fall outside the tolerance range of fish species can also lead to population declines. For example, freshwater fish are more sensitive to pH changes than marine species. Low pH can irritate fish gills, reducing oxygen uptake, while high pH levels can disrupt fish respiratory systems **(Nasir *et al.*, 2019)**.

CONCLUSION

The diversity and composition of fish species in Bone Gulf are influenced by environmental conditions at each research station. 69 fish species from 42 families were identified, with a total catch of 2,059 individuals. The diversity index showed that Station II (3.17) and Station III (3.32) had higher fish diversity than Station I (2.6), reflecting better habitat support at both stations. Environmental factors such as dissolved oxygen (DO), current velocity, pH, and salinity significantly influenced fish abundance, suggesting that environmental conditions at each station contributed to the variation in fish communities. Understanding these relationships is important for identifying different fish species' specific habitat requirements and distribution patterns.

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