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Diversity of Pelagic Fish Based on a Longline Fishery Catch in the Indian Ocean

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ABSTRACT

This study focuses on the diversity of pelagic fish species based on tuna longline catches in the Indian Ocean. Data were collected from tuna longline fishery observers between 2017 and 2021. The results showed that the catch per unit effort (CPUE) of longline vessels in the Indian Ocean during the 2017-2021 period ranged from 5.507 to 6.242, with an average of 5.768. The results identified 54 species across four groups of fish: tunas, billfishes, sharks and rays, and bony fishes. In the rainy season, the species diversity index value in all zones ranges from 2.046 to 2.628, with sea surface temperature (SST) ranging from 15.7 ℃ to 30 ℃ and sea surface chlorophyll-a (SSC) ranging from 0.03 to 1 mg/m³. The diversity index is in the moderate category in the dry season, ranging from 1.236-2.458, with SST ranging from 14 ℃-29 ℃ and SSC ranging from 0.06-1 mg/m³. The Evenness index showed high values in the rainy season, with a range of values from 0.660 to 0.773, and moderate values in the dry season from 0.420 to 0.709. Species dominant index values range from 0.097 to 0.526, and species richness index values for each season and zone are >5.

1. INTRODUCTION

Capture fisheries utilize fish resources that have economic value using complex and straightforward technology [1]. Pelagic fish resources are among the most economically significant fisheries resources in Indonesia, contributing considerably to Indonesia's fisheries sector. It lives in the surface waters from the coast to the open ocean [2].

The Indian Ocean is one of the most promising waters and is the habitat of economically important pelagic fish species in Indonesia. Pelagic fish have long been the main target of fishermen in these waters and have been landed in several locations along the coast of the Indian Ocean. Pelagic fish in Indian Ocean waters are generally caught by fishermen using tuna longlines, purse seines, troll lines, handlines, gill nets, and others. Pelagic fish resources in the Indian Ocean waters were dominated by tuna, skipjack, and mackerel from 2005 to 2014 [3]. Large pelagic fisheries accounted for 46% of the total potential fish resources, estimated at 586,128 tons per year, in Fisheries Management Area 573 of the Indian Ocean south of Java, Bali, and Nusa Tenggara [4].

Research [5] reports that in the Indian Ocean, the tuna fishery is dominated by longline vessels from IOTC member states such as Indonesia, Taiwan, China, Japan, and South Korea, with a total of 1,631 vessels. The catches of tuna longline fisheries consist of target species and bycatch. In the Indian Ocean, the target species are generally dominated by economically important tuna, including bigeye tuna, yellowfin tuna, and albacore. Meanwhile, bycatch includes billfish, sharks, rays, sea turtles, and others. Tuna fishing in the Indian Ocean is still under pressure, especially for bigeye tuna. This species is considered "overfished but not subject to overfishing," and the total catch in 2024 was 82,874 tons. Meanwhile, yellowfin tuna is showing signs of improvement, with a stock status of "not overfished and not subject to overfishing," with a total catch of 489,742 tons in 2024, and albacore has a status of "not overfished and not subject to overfishing," with a total catch of 37,006 tons in 2024 [5].

High levels of fishing concentration throughout the fishing area can lead to the depletion of fish stocks. In addition, anomalies in the aquatic environment can be a contributing factor to low catches. Research [6] stated that several oceanographic parameters, such as sea surface temperature (SST) and chlorophyll-a (SSC) concentration, contribute to variations in the migration behavior, distribution, and abundance of pelagic fish. This is due to the very dynamic nature of fish presence in waters, and naturally, fish will migrate to choose habitats that are more suitable and support their lives optimally [7].

Studies of the relationship between oceanographic conditions of waters and the pelagic fish presence, especially tuna, have so far been carried out by studies [8, 9] using oceanographic satellites, but only using Sea Surface Height Anomaly parameters. Other studies have also been conducted on the relationship of pelagic fish catches to temperature parameters and chlorophyll-a concentrations [10]. Therefore, complete and accurate information about the oceanographic characteristics of waters is handy to understand their relationship with the distribution and abundance of fish resources [11].

Longline fishing is one of the primary methods used to harvest tuna species, particularly in the Indian Ocean. Previous studies [12, 13] have shown that longlines are also valuable tools for sampling and investigating the diversity and community dynamics of pelagic species. Tracking species diversity over time can help reveal changes in ecosystem structure and function [14]. Although it is often impractical to collect comprehensive catch data for every species in multi-species fisheries, observations recorded by scientific observers aboard longline vessels provide useful information for analyzing species diversity and distribution patterns. Such data play a crucial role in assessing spatial and temporal variations in fish populations and in understanding the effects of commercial fishing activities on marine ecosystems. This information is important in evaluating the spatial-temporal variability of fish populations and the impact of commercial fisheries on fish populations [15].

Unlike previous studies relying on port-side sampling or vessel logbooks, this study uses on-board observer data collected across multiple fishing zones and seasons, providing direct and spatially resolved information on pelagic fish diversity, especially in the eastern Indian Ocean. This study will answer (1) How do catch per unit effort (CPUE) and diversity indices vary spatially (across fishing zones) and temporally (between seasons)? (2) What is the species composition and diversity of pelagic fish caught by longline vessels operating in different zones and seasons of the Indian Ocean? And (3) Is there a statistically significant association between SST, SSC, and observed diversity patterns?

2. METHODOLOGY

2.1 Study area

The research was performed in the Southeast Indian Ocean at coordinates 5°-36°N and 93°-117°E (Figure 1). The research site was divided into 4 zones based on the water characteristics and fishing habits of the Indonesian longline fleet operating in the Indian Ocean. The determination of zones will be used to investigate the abundance of species indices and their interactions with the environment in each zone. The boundaries of the 4 research zones are zone 1 in the Indonesian EEZ, zone 2 outside the EEZ up to latitude 20°S, zone 3 20.01°-30°S, and zone 4 above latitude 30.01°S.

2.2 Data collecting

2.2.1 Fisheries data

The fisheries data used in the study are scientific observer data for 2017-2021. Data coverage includes catch data per species, fishing location, number of hooks, and number of trips in 4 fishing zones. The distribution of fishing zones was as follows: Zone 1 (6 trips), Zone 2 (7 trips), Zone 3 (6 trips), and Zone 4 (6 trips).

2.2.2 Environmental data

The environmental data used are SST and SSC. The data was downloaded from https://oceancolor.gsfc.nasa.gov/ using the Aqua Moderate Imaging Spectroradiometer (MODIS) satellite sensor level 3 monthly, with a spatial resolution of 4 Km from January 2017 to December 2021. Monthly SST and chlorophyll-a values were extracted from each pixel according to the location of tuna longline fishing activity. The SPL and chlorophyll-a data were extracted using the SeaWiFS Data Analysis System (SEADAS) 7.5.3 software. To see the characteristics of the environment, SST and SSC data were used as seasonal climatology data, and there is a dry season (April-September) and a wet season (October-March). This study utilized bathymetric data obtained from the General Bathymetric Chart of the Oceans (GEBCO), which provides a geographic latitude–longitude grid with a spatial resolution of 15 arc-seconds.

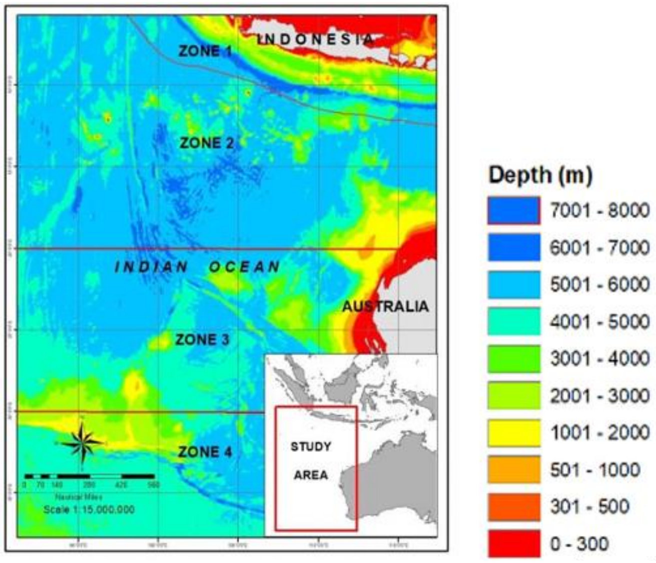


Figure 1. Study area in the Indian Ocean

2.3 Data analysis

2.3.1 Catch per unit effort

The longline tuna catches data, and the number of hooks at each fishing location were compiled monthly, and then the abundance index value was calculated. The catch abundance index is represented as longline CPUE, or the amount of catch taken per one hundred or one thousand hooks, using the following formula [16]:

$$CPUE_i = \frac{E_i}{P_i} \times 1000 \quad (1)$$

where,

Ei: the total individual fish caught in the i month

Pi:the total fishing line used in the i month

The CPUE was expressed as the number of fish caught per 1,000 hooks set. No formal standardization was applied to control for vessel-specific factors, hook depth, or gear configuration, as these data were not consistently recorded across all observed trips. This represents a limitation of the study, as differences in fishing power between vessels may contribute to variance in CPUE estimates. Future studies should incorporate vessel-specific covariates in a GLM-based standardization framework. The CPUE abundance index determines the level of resource exploitation in a water area. This study uses CPUE as an indicator of fish availability for longline fisheries within a specific area.

2.3.2 Fish diversity, evenness, and dominance indices

Furthermore, this study will estimate the diversity, evenness, and dominance of large pelagic fish species caught by longlines in the Indian Ocean. To obtain the fish diversity, the catches were identified and counted. Fish species diversity is influenced by both the number of species present and the relative abundance of individuals within each species. Higher diversity values indicate a greater variety of species in the community and are strongly affected by the distribution and total abundance of individuals among different species or genera. The diversity of fish species was estimated using the Shannon–Wiener diversity index (H′) [17, 18], fish species richness was measured by the Margalef Index (d) [19], evenness was calculated by the Pielou index (J′) [20], and species dominance was calculated by the Simpson index (C) [21]. Calculation of all index values uses the following formula:

a) Shannon-Weiner diversity index (H')

$$H' = -\sum_{i=1}^{s} p_i \ln p_i \quad (2)$$

$$p_i = \frac{n_i}{N} \quad (3)$$

where,

H': Shannon-Wiener species diversity index

n_i:number of individuals of the i species

N: total number of individuals caught

Criteria for diversity results based on Shannon-Wiener:

$H' < 1$: low species diversity

$1 < H' < 3$: medium species diversity

$H' > 3$: high species diversity

b) Pielou's evenness index (E)

$$E = \frac{H'}{\ln (S)} \quad (4)$$

where,

H': the Shannon Wiener index

S: total fish species

The categories of evenness index values are as follows:

$0 < E \leq 0.4$: little evenness, stressed community

$0.4 < E \leq 0.6$: moderate evenness, unstable community

$0.6 < E \leq 1.0$: High evenness, stable community

c) Simpson dominance index (C)

$$C = \sum_{i=1}^{s} (\frac{n_i}{N})^2 \quad (5)$$

where,

C: dominance index

n_i: number of individuals of the i species

N: total number of individuals caught

S: total fish species

The dominance index value ranges from 0-1 with the following categories:

$0 < C \leq 0.5$: low dominance

$0.5 < C \leq 0.75$: medium dominance

$0.75 < C \leq 1.0$: high dominance

The greater the dominance index (C) value, the greater the tendency for a particular species to dominate.

d) Margalef species richness (d)

$$d = \frac{(S-1)}{\log (N)} \quad (6)$$

where,

S: total fish species

N: total number of individuals caught

To see any differences in the diversity values of each fishing trip, the analysis of variance (ANOVA) test was conducted. ANOVA is a statistical analysis that compares the means of several samples. ANOVA is an extension of the t-test for two independent samples to more than two groups. The assumptions required in performing the ANOVA procedure are:

a. Observations are independent of each other.
b. The observations in each group come from a normal distribution.
c. The population variance in each group is the same (homoscedasticity).

The hypothesis in the ANOVA is as follows:

$H0$: $\mu_1 = \mu_2 = \ldots = \mu k$

$H1$: there is at least one unequal

Decision-making by comparing F_{count} with F_{table}:

If $F_{count} > F_{table}$: reject H0

If $F_{count} \leq F_{table}$: accept H0

Prior to ANOVA, data normality was tested using the Shapiro-Wilk test ($p > 0.05$ in all cases), and homogeneity of variance was verified using Levene's test. All statistical analyses were performed using Excel and R version 4.3.1.

Although the number of observed trips was not perfectly equal across zones, sample sizes were broadly comparable. To account for potential unbalanced design, a Welch's ANOVA was also performed as a robustness check; results were consistent with the standard one-way ANOVA.

3. RESULTS AND DISCUSSION

3.1 Catch per unit effort

One indicator of stock assessment in pelagic fisheries management is determining the abundance index based on CPUE. The CPUE ratio of pelagic fish with longline gear in the Indian Ocean fluctuated between 5.507 and 6.242, averaging 5.768. The highest CPUE was in 2018 and then decreased from 2018 to 2021 (Figure 2). This average CPUE value is higher than the CPUE value in 2013-2014 [22].

This decrease in CPUE may indicate that the availability of fish resources has begun to decrease, since CPUE is commonly used as a proxy for relative stock abundance under the assumption that catchability remains constant over time [23]. However, this relationship should be interpreted with caution, as catch rates do not always change proportionally with true abundance. The average CPUE value in 2019-2021 tends to be higher than in previous years. This condition is not only caused by differences in factors that affect the CPUE value, as mentioned earlier, but also due to the number of vessels operating and indications of entrustment of catches using transport vessels. The 2012-2014 study results showed that fishing effort was positively correlated with the number of vessels operating and with an increase in the frequency of depositing catches using transport vessels [24, 25]. On the other hand, there are also differences in environmental conditions and ecological factors, as described by research [26]. Seasonal differences in CPUE are influenced by changes in environmental conditions (temperature, salinity, currents) and various ecological processes, including migration patterns, food resources, predation, recruitment, and fishing intensity. According to a study [27], catch rates and fishing effort are affected by the quantity of fishing gear deployed, operational efficiency, the length of time of fishing operations, fish availability, weather conditions, and the aquatic environment.

3.2 Species composition

Longline catches generally consist of target species and bycatch, both economic value (by-product) and non-economic value (discard). Based on the results of scientific observer records on board during 2017-2021, the types of fish caught by longlines operating in the Indian Ocean are categorized into tunas (6 species), billfishes (6 species), sharks and rays (20 species), and bony fishes (22 species). Of the total catch, the bony fish group dominated the catch at 51.26%, followed by the tuna group at 33.44%. Based on species, the catch was dominated by longnose lancetfish (*Alepisaurus ferox*) (27.01%), followed by albacore (*Thunnus alalunga*) (17.65%) and escolar (*Lepidocybium flavobrunneum*) (13.78%) (Table 1). Longnose lancetfish was the discard catch, albacore was the main catch, and escolar was the by-product catch.

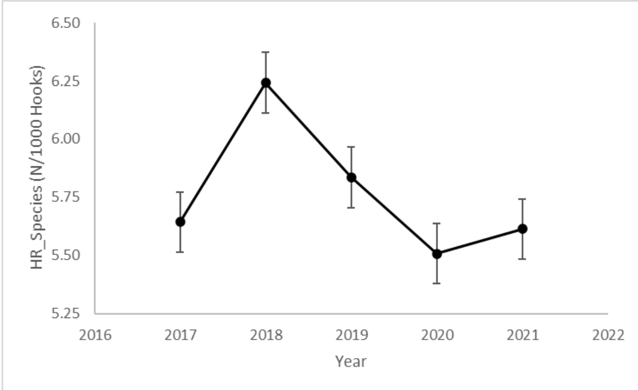


Figure 2. The yearly catch per unit effort (CPUE) ratios (catches per 1,000 hooks) were estimated for all species

Table 1. Composition of longline catches operating in the Indian Ocean, 2017-2021

No.	Scientific Name	2017	2018	2019	2020	2021	Total	%
	Tunas	**824**	**1445**	**1646**	**492**	**1802**	**6209**	**33.44**
1	*Thunnus alalunga*	177	864	785	183	1269	3278	17.65
2	*Thunnus obesus*	309	285	276	200	168	1238	6.67
3	*Thunnus albacares*	58	122	362	37	181	760	4.09
4	*Thunnus maccoyii*	271	95	166	8	150	690	3.72
5	*Katsuwonus pelamis*	9	79	57	64	32	241	1.30
6	*Thunnus* spp.	-	-	-	-	2	2	0.01
	Billfishes	**83**	**161**	**297**	**66**	**129**	**736**	**3.96**
7	*Xiphias gladius*	68	93	161	28	61	411	2.21
8	*Istiophorus platypterus*	6	7	64	1	16	94	0.51
9	*Makaira mazara*	3	28	25	6	19	81	0.44
10	*Istiompax indica*	-	12	34	19	12	77	0.42
11	*Tetrapturus angustirostris*	6	9	9	4	11	39	0.21
12	*Kajikia audax*	-	12	4	8	10	34	0.18
	Sharks and Rays	**-**	**753**	**623**	**204**	**526**	**2106**	**11.34**
13	*Pteroplatytrygon violacea*	-	230	239	69	280	818	4.41
14	*Prionace glauca*	-	300	223	107	143	773	4.16
15	*Pseudocarcharias kamoharai*	-	148	122	9	66	345	1.86
16	*Alopias superciliosus*	-	15	4	13	14	46	0.25
17	*Carcharhinus longimanus*	-	10	6	2	9	27	0.15
18	*Carcharhinus falciformis*	-	12	10	-	5	27	0.15
19	*Isurus oxyrinchus*	-	13	6	2	4	25	0.14
20	*Isurus paucus*	-	5	3	-	1	9	0.05
21	*Isistius brasiliensis*	-	9	-	-	-	9	0.05
22	*Galeocerdo cuvier*	-	3	4	-	1	8	0.04
23	*Alopias pelagicus*	-	2	3	-	-	5	0.03
24	*Carcharhinus limbatus*	-	-	3	1	-	4	0.02
25	*Carcharhinus obscurus*	-	2	-	-	-	2	0.01
26	*Sphyrna zygaena*	-	1	-	1	-	2	0.01
27	*Carcharhinus brachyurus*	-	-	-	-	1	1	0.005
28	*Negaprion acutidens*	-	-	-	-	1	1	0.005
29	*Lamna nasus*	-	1	-	-	-	1	0.005
30	*Isurus* spp.	-	-	-	-	1	1	0.005
31	*Sphyrna lewini*	-	1	-	-	-	1	0.005
32	*Mobula mobula*	-	1	-	-	-	1	0.005
	Bony Fishes	**619**	**2809**	**1810**	**1167**	**2393**	**9518**	**51.26**
33	*Alepisaurus ferox*	89	1760	657	690	1099	5015	27.01
34	*Lepidocybium flavobrunneum*	244	613	669	253	779	2558	13.78

35	*Gempylus serpens*	26	65	110	110	207	518	2.79
36	*Lampris guttatus*	16	57	158	56	73	360	1.94
37	*Taractichthys steindachneri*	105	131	25	18	38	317	1.71
38	*Acanthocybium solandri*	30	74	80	23	85	292	1.57
39	*Taractes rubescens*	42	45	11	5	14	117	0.63
40	*Coryphaena hippurus*	34	11	33	4	15	97	0.52
41	*Ruvettus pretiosus*	24	19	20	5	16	84	0.45
42	*Lophotus capellei*	1	7	7	1	15	31	0.17
43	*Sphyraena* spp.	-	2	15	-	11	28	0.15
44	*Brama brama*	-	2	19	1	6	28	0.15
45	Bramidae	-	2	1	-	17	20	0.11
46	*Trachipterus* spp.	7	9	-	-	2	18	0.10
47	*Elagatis bipinnulata*	-	4	-	-	5	9	0.05
48	*Trichiurus* spp.	-	2	3	-	3	8	0.04
49	*Gasterochisma melampus*	-	-	-	-	7	7	0.04
50	*Mola mola*	-	3	2	1	-	6	0.03
51	*Eumegistus illustris*	1	1	-	-	-	2	0.01
52	*Harriette* spp.	-	1	-	-	-	1	0.005
53	*Lagocephalus macrocephalus*	-	1	-	-	-	1	0.005
54	*Trachichthys australis*	-	-	-	-	1	1	0.005
	Total	**1526**	**5168**	**4376**	**1929**	**4850**	**18569**	**100**

The results of scientific observer records in 25 trips in 4 fishing zones during 2017-2021 obtained fish species between 19 and 47 species, with more than 1700 fish per trip. The number of species in each zone differs in the wet and dry seasons. For zones 1 and 2, the number of fish in the wet season tends to be less than in the dry season. However, this condition is inversely proportional to the fishing zones in zones 3 and 4 (Figure 3).

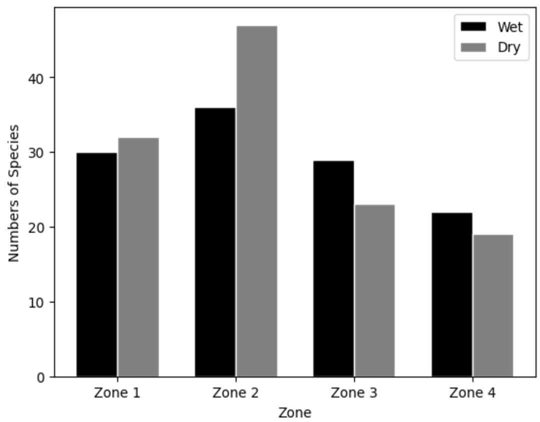


Figure 3. Number of fish species caught per zone and season

The composition of fish species caught in each zone and fishing season differs. The composition of the catch in zone 1 wet season is dominated by yellowfin tuna (*Thunnus albacares*) at 16.69%, then pelagic stingray (*Pteroplatytrygon violacea*) at 13.96%, and longnose lancetfish at 13.05%. In comparison, in the dry season, the fish species are dominated by yellowfin tuna 22.91%, albacore 18.21%, and pelagic stingray 10.54%. In zone 2, the catch was dominated by longnose lancetfish with a percentage of 28.20%, albacore at 17.16%, and escolar at 13.18% in the wet season, while in the dry season, the dominant fish caught was longnose lancetfish with 30.67%, escolar 15.16%, and albacore 13.47%. Different case with the dominant fish in zone 3, which in the wet season is longnose lancetfish 30.16%, escolar 18.42%, and albacore 16.33%, and for the dry season is longnose lancetfish 45.27%, escolar 16.28%, and albacore 9.30%. The catch in zone 4 is quite different, with the largest composition for the wet and dry seasons, where in both seasons, it shows different types of fish for the largest catch, namely southern bluefin tuna (*Thunnus maccoyii*) 34.75% in the wet season, and albacore 71.78% in the dry season. This was followed by blue shark (*Prionace glauca*) 18.77% and albacore 16.11% in the wet season. While in the dry season, escolar 5.7% and opah fish (*Lampris guttatus*) 5.49% (Figure 4). By species group, albacore dominate in the tuna species group, while swordfish dominate in the billfishes species group. By shark and ray species group, blue sharks dominate the shark species, and pelagic stingrays dominate the ray species. Meanwhile, the bony fishes species group is dominated by longnose lancetfish (Figure 5).

The catches from 2017-2021 were dominated by longnose lancetfish at 27.01%, albacore at 17.65%, and escolar at 13.78%. The dominance of longnose lancetfish catches is thought to be because this fish spreads in almost all waters in the world (tropical and subtropical), inhabiting the mesopelagic zones of the Pacific Ocean, Atlantic Ocean, and Indian Ocean, except in polar regions, studies [28] have reported catches of longnose lancetfish in the Indian Ocean, studies [29] in the Western Pacific Ocean, study [30] in the Eastern Pacific (from the Aleutian Islands to Chile), study [31] in the Western Atlantic (from the Gulf of Maine to the Gulf of Mexico and the Caribbean Sea), and study [32] in the Northwest Atlantic (Canadian waters). It is an incidental catch in tuna and swordfish longline fisheries [33, 34]. Even study [35] stated that fishery observer data showed longnose lancetfish was the most frequently caught species in Hawaii-based longline fisheries between 2005 and 2015.

Meanwhile, the dominance of albacore catches is thought to be due to the Indian Ocean being a suitable habitat for albacore. According to studies [36, 37], albacore is found in temperate and tropical waters in the Indian, Pacific, and Atlantic Oceans. In the Atlantic, its geographical boundaries are 45-50°N and 30-40°N, while in the Indian Ocean, its distribution ranges from 5°N to 40°N, with adult fish emerging from 5°N to 25°N. Studies [38, 39] reported that the distribution of albacore in the Indian Ocean exhibits seasonal variation. Juvenile albacore is generally concentrated in the southern Indian Ocean throughout the year, as the cooler water temperatures in this region provide more favorable habitat conditions than those found in the central Indian Ocean.

The dominance of escolar catches is also thought to be because the Indian Ocean is a suitable habitat for escolars such as longnose lancetfish and albacore. These fish are widely distributed in tropical and subtropical (sometimes temperate) waters of the eastern Indian Ocean, western Pacific, and western Central Atlantic. It is a meso or bathypelagic species and resides mainly on the continental slope to depths of 200 m or more. It often migrates upwards at night [40]. The results of the study [41] used remote sensing, and the favorable habitat for escolars is in the southwestern Indian Ocean waters.

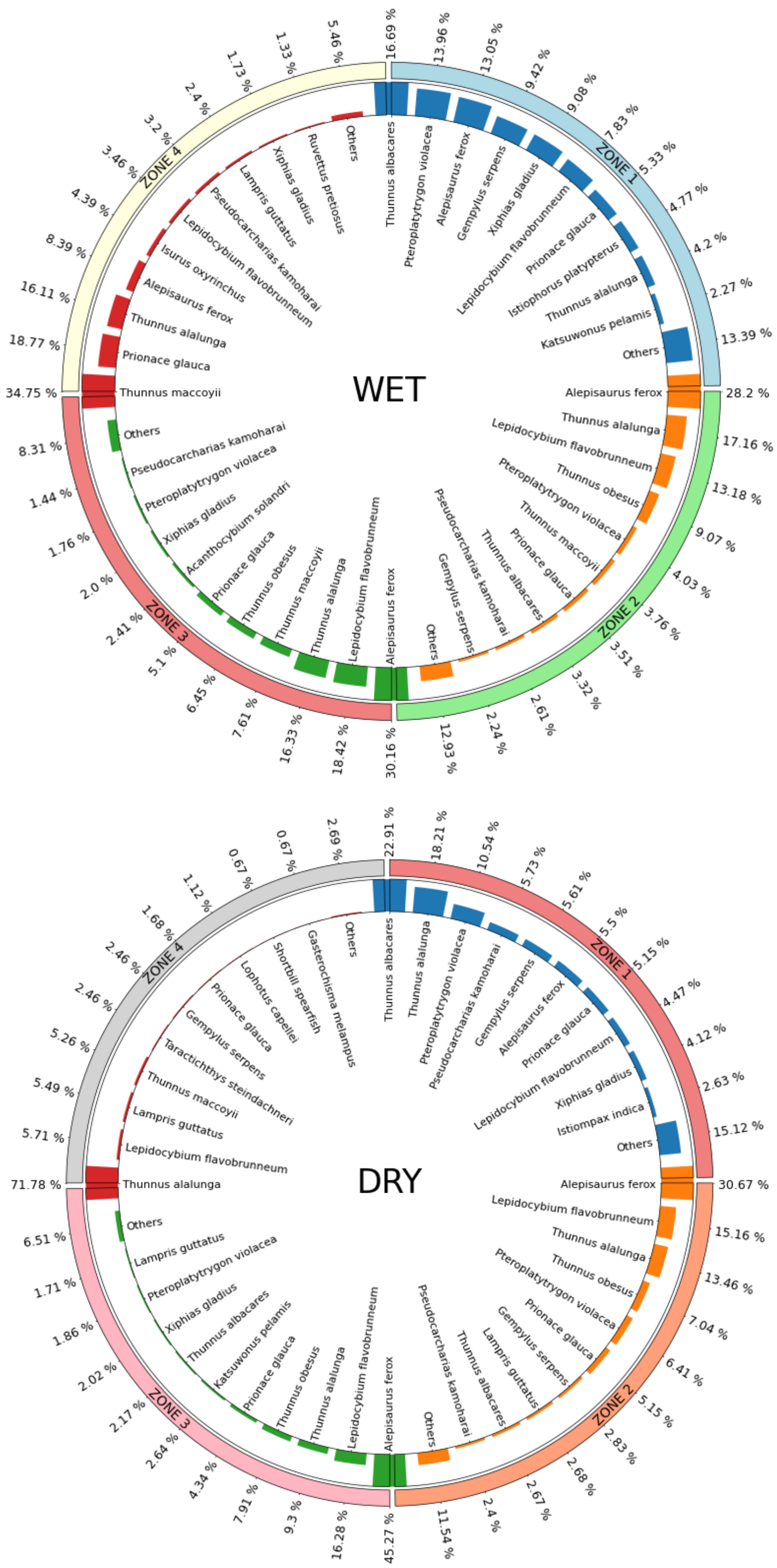
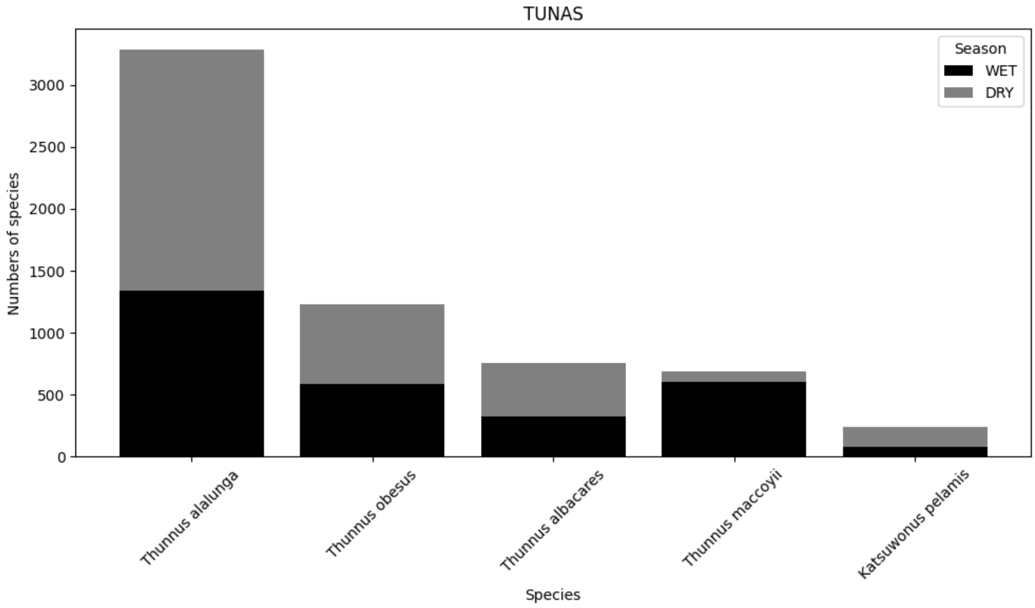
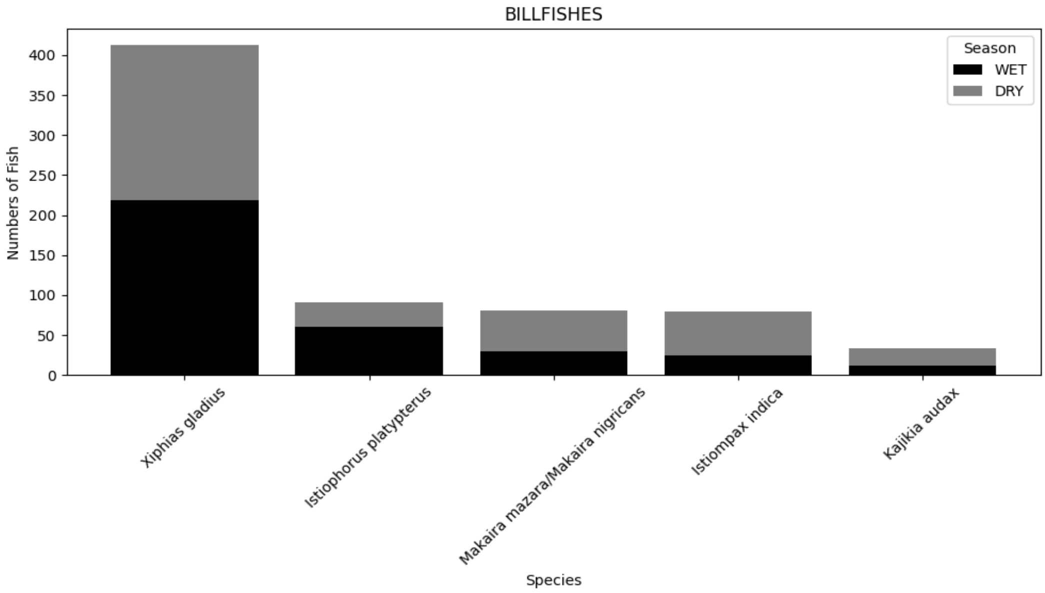
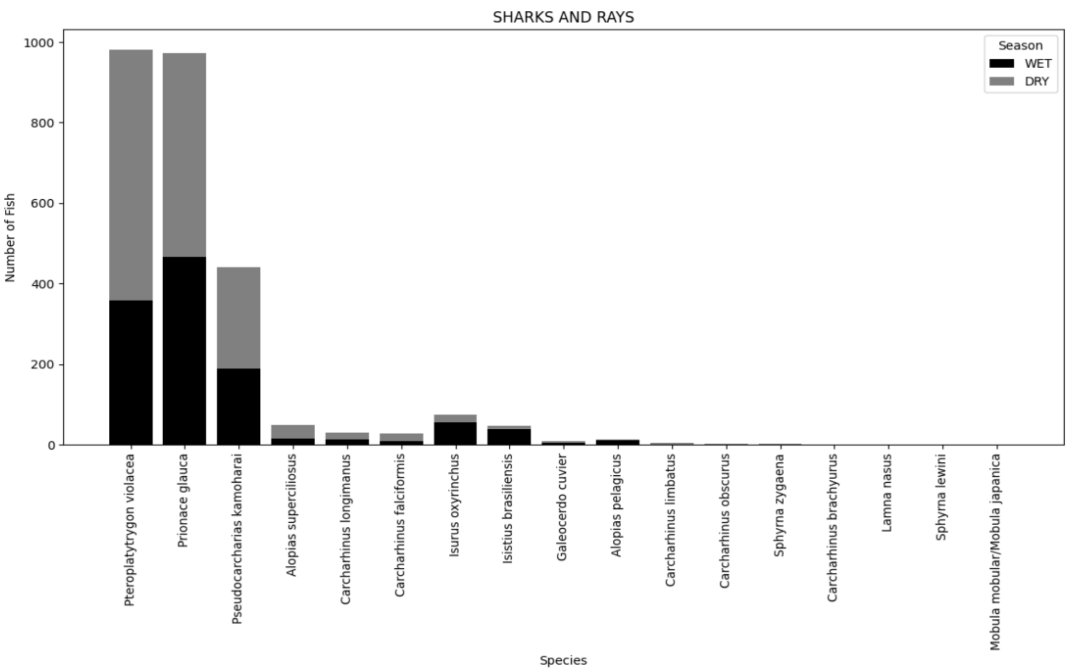


Figure 4. Fish species composition by species per season


TUNAS
Season
WET
DRY
Numbers of species
0
500
1000
1500
2000
2500
3000
Thunnus alalunga
Thunnus obesus
Thunnus albacares
Thunnus maccoyii
Katsuwonus pelamis
Species


BILLFISHES
Season
WET
DRY
Numbers of Fish
0
50
100
150
200
250
300
350
400
Xiphias gladius
Istiophorus platypterus
Makaira mazara/Makaira nigricans
Istiompax indica
Kajikia audax
Species


SHARKS AND RAYS
Season
WET
DRY
Number of Fish
0
200
400
600
800
1000
Pteroplatytrygon violacea
Prionace glauca
Pseudocarcharias kamoharai
Alopias superciliosus
Carcharhinus longimanus
Carcharhinus falciformis
Isurus oxyrinchus
Isistius brasiliensis
Galeocerdo cuvier
Alopias pelagicus
Carcharhinus limbatus
Carcharhinus obscurus
Sphyrna zygaena
Carcharhinus brachyurus
Lamna nasus
Sphyrna lewini
Mobula mobular/Mobula japanica
Species

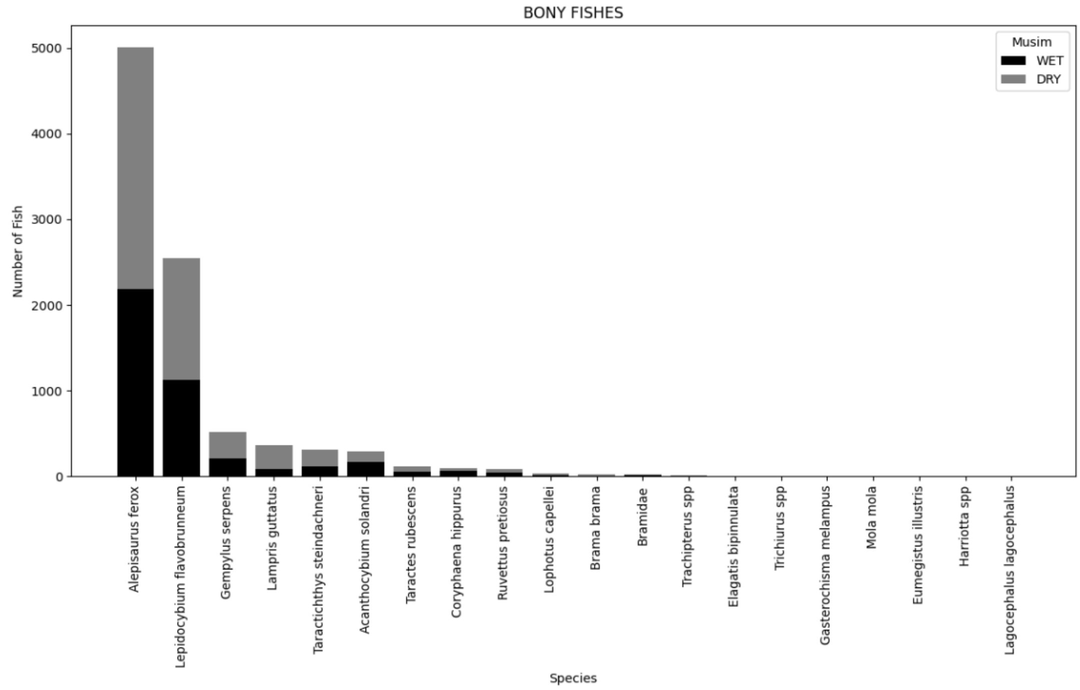


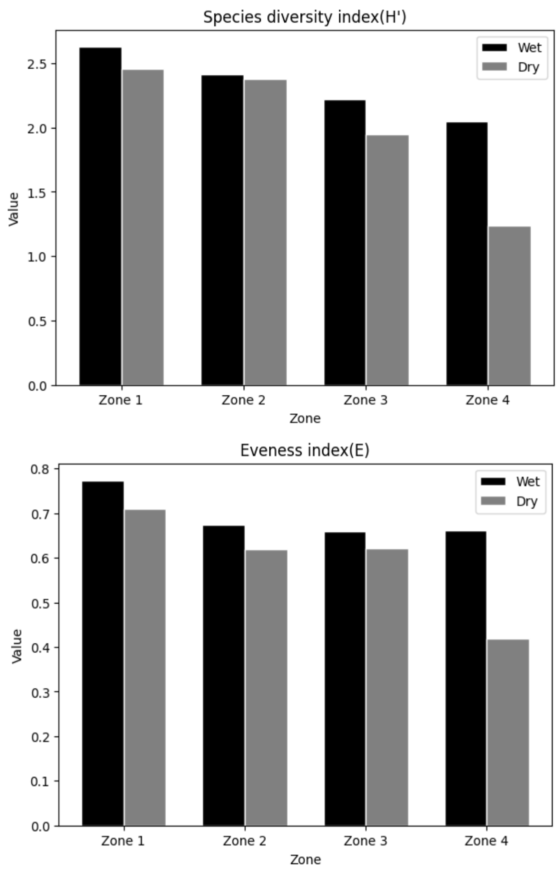
Figure 5. Number of fish by group (tunas, billfishes, sharks and rays, and bony fishes) caught per season

Furthermore, Fishers generally prefer to operate in areas characterized by high fish concentrations and tend to revisit the same fishing grounds while catch rates remain satisfactory. However, when catches decline and profitability is reduced, fishing effort is often redirected to more productive areas [42]. The selection of fishing grounds is closely associated with the migratory behavior of fish species, as fishers target areas where fish populations are densely aggregated. Seasonal migrations and habitat use are largely driven by oceanographic conditions and the availability of food resources [43, 44]. Because the Indian Ocean is characterized by substantial environmental fluctuations, favorable oceanographic conditions during the observed period may have enhanced fish abundance and supported higher catch rates [45, 46].

3.3 Spatial and temporal distribution of abundance and diversity

Fish diversity, evenness, and dominance are parameters that can be used to analyze the structure of the fish community in a water area. Analysis of the diversity index and diversity index results will show that the distribution pattern of fish within a marine area can be described through community structure analyses, while the dominance index identifies species that are predominant in the ecosystem. The results of several fish community structure parameters for species caught in the Indian Ocean in 4 zones and seasons are shown in Figure 6.

Figure 6 shows the results of calculating several parameters of the community structure of fish caught in the Indian Ocean, which is divided into 4 zones, and each zone is divided into 2 seasons, namely wet and dry seasons. Diversity index values in the wet season in the four zones ranged from 2.046 to 2.628, while in the dry season, they ranged from 1.236 to 2.458. Zone 1 exhibited the highest diversity index value in the wet season, and zone 4 had the lowest diversity index in the dry season. Based on the value of the Shannon-Wiener diversity criteria, it can be said that the diversity index is medium in each season and zone, meaning that no one has a low or high diversity index value. The results of this study differ slightly from those reported for the Pacific Ocean [47] and the Indian Ocean south of East Java [48]. The results of research [47] showed diversity index values ranging from 0.82 to 1.47, and research [48] showed values ranging from 0.0 to 1.50. Based on the Shannon-Wiener diversity index, both studies suggest that species diversity ranges from low to moderate levels.



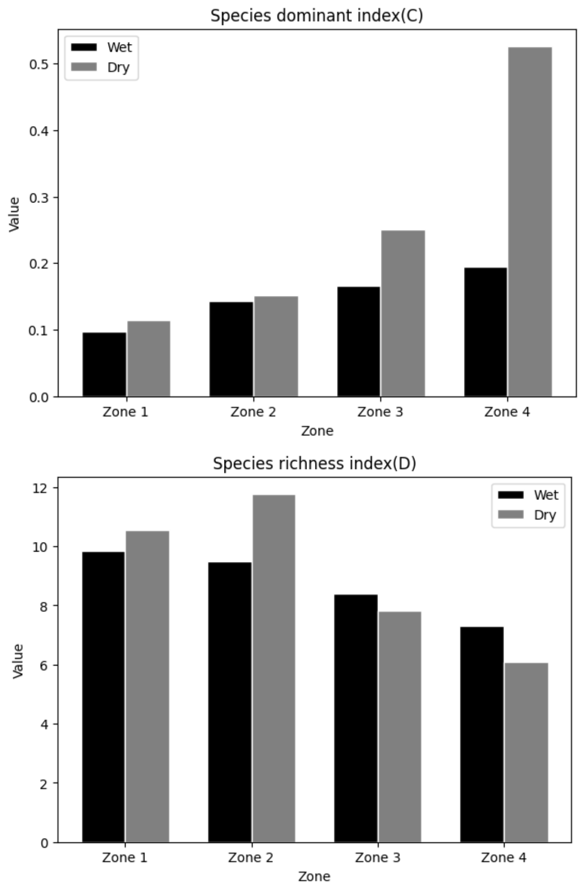


Figure 6. The values of species diversity, species evenness, species dominance, and species richness indices for each zone and season

Furthermore, the calculation results of the evenness index in the wet season in each zone ranged from 0.660 to 0.773, while the evenness index in the dry season in each zone ranged from 0.420 to 0.709. Based on a comparison between the calculated values and the evenness criteria values, two criteria of evenness index are used: moderate evenness in the dry season and high evenness in the wet season. The results of this evenness index analysis indicate that there is no dominating fish species, and it can be said that the distribution of the number of individuals in the Indian Ocean waters is relatively even. The distribution of individuals across species in the Indian Ocean is relatively uniform, while the dominance index reflects the degree to which certain species dominate and their distribution patterns within the ecosystem. Samad et al. [49] state that a highly even distribution has an E value close to 1, meanwhile a value close to 0 indicates strong dominance by one or more species. The dominance index of fish caught in the Indian Ocean has different values. The highest dominance index value was found in zone 4, dry season, with a value of 0.526, while the lowest was in zone 1, wet season, with a value of 0.097. The dominance index value for each zone is mainly in the low dominance category because it is indicated by the dominance value less than or equal to 0.5, except in zone 4 in the dry season, which has a value of 0.526. This shows that the fish caught in the Indian Ocean do not have dominating fish species.

Further analysis is related to the fish species richness index, which is the value or ratio of the species ratio between the total number of species and the number of individual species found at the research location. Based on data analysis of fish species richness in the Indian Ocean, the species richness index value in each zone and season is more than 5. Based on the species richness index value criteria, if the value of $D < 3.5$ is in the low category, $3.5 < D < 5$ is in the medium category, and $D > 5$ is in the high species richness category. The results of the species richness index value calculation with a value of more than 5 indicate that the index of fish species richness in the Indian Ocean is included in the criteria for high fish species richness.

A Shapiro–Wilk normality test was conducted before applying ANOVA to verify the distribution of the data. The test indicated that all variables followed a normal distribution ($p > 0.05$ for all groups) [50]. The homogeneity of variances across groups was verified using Levene's test [51], and the assumption of homoscedasticity was met before further analysis was conducted.

The ANOVA results (Table 2) show that the P-value for diversity and dominance indices is greater than the value of the real level (0.05). It can be said that there is no significant difference between season and zone, nor is there any interaction between season and zone regarding the diversity and dominance of fish. In other words, differences in season and zone do not affect the diversity and dominance of fish caught in the Indian Ocean. In contrast, the number of fish caught in each zone has a P-value that exceeds the real level value, so it can be said that the fishing zone is in the Indian Ocean.

Table 2. Analysis of variance (ANOVA) test analysis results

Test	No. of Species			Diversity Index (H′)			Dominance Index (C)		
	Zone	Season	Zone: Season	Zone	Season	Zone: Season	Zone	Season	Zone: Season
F	9.0284	0.1771	1.1184	1.1183	1.2281	0.4381	4.039e-01	1.183e-32	5.266e-31
P-value	0.00001	0.6741	0.3414	0.3514	0.2797	0.7262	0.7503	1.00000	1.000000
Decision	Accept H0	Reject H0	Reject H0	Reject H0	Reject H0	Reject H0	Reject H0	Reject H0	Reject H0

The study of diversity, evenness, dominance, and richness of longline caught fish species in the Indian Ocean was conducted using the Shannon-Wiener index (H′), Pielou index (E), Simpson index (C), and Margalef index (d). The four indices were calculated in four fishing zones and two seasons, namely the wet and dry seasons. The results showed that the diversity index values were at a moderate stage for all four zones and both seasons, but the diversity index values in the wet season tended to be higher than in the dry season.

The value of the evenness index shows the difference in evenness in the wet and dry seasons, where the calculation of the evenness index in the dry season shows a smaller index value than the evenness index value in the wet season. Nevertheless, the evenness index analysis results have a value that tends to approach the value of 1, namely 0.773, which indicates that no fish species dominate in Indian Ocean waters.

This follows the statement of research [52], which says that an ecosystem tends to a particular species if the evenness value is close to 0, while if the evenness index value is close to 1, it shows that the ecosystem is fixed, and the number of individuals is evenly distributed among each species. The above condition is in line with the dominance index value, which shows that the fish caught in the Indian Ocean do not have a dominating fish species.

The criteria for the value of diversity and dominance of fish species in the Indian Ocean are reinforced by the results of statistical analysis calculations showing no significant difference in the level of diversity and evenness/dominance in the season or fishing zone. It can be stated that differences in season and fishing zone do not affect the level of diversity and dominance of fish caught in the Indian Ocean. This study's results align with the longline fishery in the Persian Gulf, previous studies have reported no significant differences in fish assemblage composition between the spring and winter seasons [53]. Similarly, longline fishery research conducted in the North Pacific Ocean found no significant variation in species richness or Shannon–Wiener (S–W) diversity index values between the northern and southern sampling areas [15]. This pattern may be attributed to the fact that longline fishing is commonly conducted in tropical and coral reef-associated environments, where species composition tends to be relatively similar [53].

3.4 Oceanographic conditions by spatial (Zones: Zones 1, 2, 3, and 4) and temporal (Seasons: Wet and dry seasons)

Indonesian waters influenced by the monsoon are visible in changes in SST in the dry and wet seasons. SST conditions in the wet season as a whole range from 15.7-30 °C, where each zone has a different SST range. Sequentially, SST in zone 1 to zone 4 are 28.7-30 °C; 25-29.8 °C; 20.8-27.8 °C; 15.7-22 °C. The range of SST in the dry season ranges from 14-29 °C, and each zone has sequential values of 27-29 °C, 24-29.1 °C, 19-26.2 °C, 14-21 °C, and to the south, the temperature decreases. In the dry season, the SST decreases (Figure 7).

The horizontal distribution of chlorophyll-a concentration shows that, in general, chlorophyll-a concentration is higher around the coast and decreases away from the coast. Chlorophyll-a concentrations in the wet season ranged from 0.03-1 $mg/m^{3,}$ with values in each zone sequentially being 0.1-1 mg/m^3; 0.05-0.2 mg/m^3; 0.03-1 mg/m^3; 0.05-0.25 mg/m^3. Chlorophyll-a concentrations during the dry season ranged from 0.06-1 $mg/m^{3,}$ with values in each zone in order of 0.12-1 mg/m^3, 0.07-0.4 mg/m^3, 0.06-1 mg/m^3, 0.1-0.6 mg/m^3 (Figure 7).

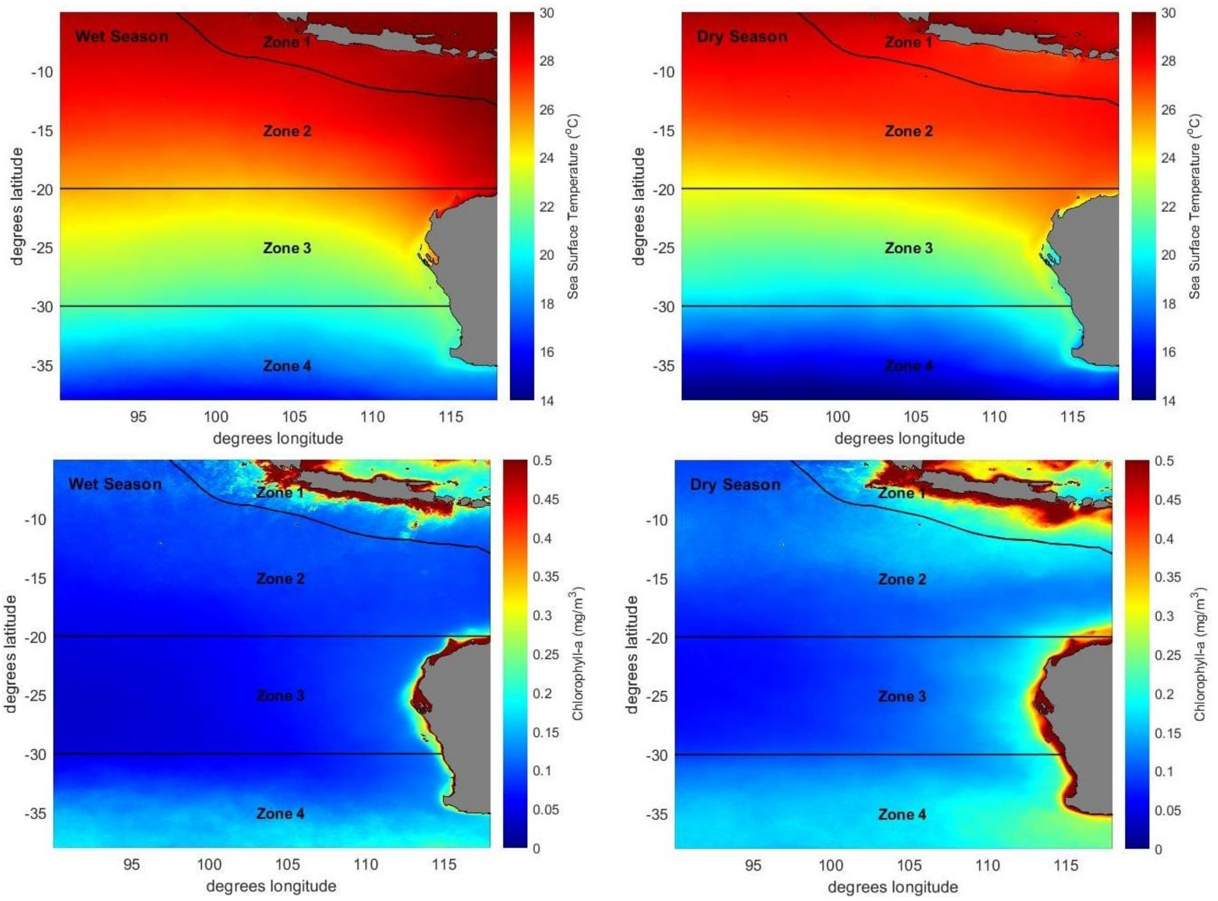


Figure 7. Average seasonal spatial distribution of sea surface temperature (SST) and chlorophyll-a (SSC) in the Southeast Indian Ocean

Based on the data on the number of fish species and STT, the further south the fishing location is, the greater the temperature decreases, and the fewer fish species are caught in both the wet and dry seasons. This shows a positive relationship between the number of fish and temperature. The abundance and spatial distribution of many pelagic fish species in the Indian Ocean are strongly influenced by STT [54]. In the study [47], biodiversity reached its highest levels in the eastern Pacific Ocean, where warm STT (24-27 °C), elevated chlorophyll-a concentrations (>0.2), and sea surface height (>0.15).

Tanjung et al. [55] stated that SST affects fish growth, activity and movement, distribution, abundance, schooling, maturation, fertility, spawning, incubating, and hatching of eggs, and the survival rate of fish larvae. According to research [56], the existence of pelagic fish resources is highly dependent on environmental factors (oceanographic conditions and food availability), so that abundance fluctuates greatly in a body of water. Very small changes in water temperature (± 0.02 °C) can cause changes in the density of fish populations in these waters.

4. CONCLUSIONS

The CPUE of longline vessels in the Indian Ocean during the 2017-2021 period with trend that tends to decrease. Longline catches identified 54 species, dominated by longnose lancetfish. Longnose lancetfish was the discard catch. The diversity index values were at a moderate stage for all four zones and both seasons, but the diversity index values in the wet season tended to be higher than in the dry season. Based on the data on the number of fish species and SST, the further south the fishing location is, the greater the temperature decreases, and the fewer fish species are caught in both the wet and dry seasons. This shows a positive relationship between the number of fish and temperature.

These findings have practical implications for the management of longline fisheries in the Indian Ocean. Higher biodiversity in Zone 2 during the rainy season identifies this area as a potential focus zone for biodiversity monitoring. We recommend that future monitoring programs include systematic environmental sampling to enable stronger spatio-temporal modeling of pelagic fish diversity in the region.

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