

Exploring the diversity of trawl catch composition in Mumbai coastal waters through experimental trawling

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Abstract

The primary focus of our experimental trawling, was to analyse fish composition within specific coordinates (19°06'66" to 19°12'15.09" north latitude, 72°41'23.20" to 72°48'50" east longitude) at depths ranging from 6 to 21 m. We catalogued 127 species comprising 34 shellfish (25 genera, 9 orders and 27 families) and 92 finfish (68 genera, 40 families, 14 orders). Dominant fish orders were Perciformes (74%), Clupeiformes (19%) and Tetraodontiformes (7%), while Decapoda led shellfish (81%) followed by Neogastropoda (19%). Discards contributed 59%, non-target 34% and target catch 7%. Species peaked 18 m (66), followed by 12-15 m (60) and dropped at 6-9 m (36). Monthly averages for discard (4.5 to 24.75 kg h⁻¹) and commercial catch (4.1 to 12.2 kg h⁻¹) fluctuated. Cluster analysis showed high similarity in species and abundance between adjacent months. Bycatch varied seasonally, lowest in winter and highest in post-monsoon. Biodiversity indices indicated rich, evenly distributed diversity. These findings yield vital insights into fish catch composition, distribution, and bycatch diversity. They are crucial for sustainably managing overexploited fisheries, forming a foundational resource for effective and sustainable exploitation.

Introduction

India ranks 17th among the megabiodiversity nations worldwide, with a remarkable 7.8% of the planet's documented species, despite covering only 2.5% of the global land area (Kumar 2011). The total global fish production reached 178.5 million t in 2018 (FAO 2020). Notably, in 2014, the estimated global marine fish bycatch amounted to 9.1 million t, with bottom trawlers responsible for 46% (4.2 million t) of this total, equivalent to 10.8% of the overall marine fish production (Perez Roda, 2019). Unfortunately, in various regions worldwide, marine fish stocks have been exploited indiscriminately, leading to severe consequences for biodiversity (Namboothri *et al.*, 2012). Fishing activities have a significant impact on the marine ecosystem, resulting in the removal of fish and benthic communities and leading to adverse environmental effects (Dayton *et al.*, 1995; Auster and Langton, 1998). Since 1970, the consequences of fishing have had far-reaching effects. According

to estimates by the Food and Agriculture Organisation, 52% of the world's fish stocks are now fully exploited, while 28% are overexploited or depleted and 20% are moderately exploited. Alarming, only 1% of these stocks show signs of recovery (FAO, 2009). Fishing plays a pivotal role in transforming marine ecosystems, with particular attention focused on trawling due to its low selectivity and impact on the seabed (Pascoe, 1997). The irrational use of trawling has resulted in evident physical degradation of marine ecosystems, marking it as a major human-induced physical and biological disturbance on the world's continental shelves in recent years (Jennings and Kaiser, 1998). Commercial fishing, particularly the indiscriminate exploitation of non-target organisms, constitutes one of the most serious threats to the world's existing populations of fish (Worm *et al.*, 2006). With a few exceptions, global fisheries have historically suffered from overexploitation or under-exploitation (Pauly and Zeller, 2016). Significant removal of unrecorded biomass may lead to resource



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depletion (Davies *et al.*, 2009) and have detrimental effects on biodiversity (Alverson and Hughes, 1996). The deep-sea bottom trawling boom of the late 20th century, spurred by shrinking shallow water fisheries and technological breakthroughs, had far-reaching effects (Koslow *et al.*, 2000). This shift led to an increased demand for non-targeted species, as the targeted species decreased and seafood consumption rose (Kelleher, 2005). Non-targeted species have become crucial for sustaining livelihoods and ensuring food security in fishery-dependent countries like India (Lobo 2007; Gupta *et al.*, 2020).

India holds Exclusive Economic Zone (EEZ) rights over a vast expanse of 2.02 million sq km, boasting a coastline stretching 8,129 km. India's fishing industry is crucial to the country's socioeconomic growth since it generates a large amount of foreign exchange from exports, national income, job opportunities and nutritional security. Trawling stands out as the predominant fishing method along the north-west coast of India, constituting approximately 56% of the total catch (CMFRI, 2011). In the fiscal year 2018-19, Indian marine fisheries emerged as one of the nation's largest industries, employing 14.50 million people and generating foreign exchange earnings exceeding ₹45,106.89 crores (DAHDF, 2019). The total marine fish landings for India in 2019-20 are estimated at 3.56 million t, with Maharashtra accounting for an estimated 2.01 lakh t of marine fish landings (CMFRI, 2020). The trawler fleet along India's north-west coast, numbering 17,195 trawlers (CMFRI, 2012), predominantly targets four key resources demersal fishes *viz.*, shrimp, cephalopods and ribbonfish. Maharashtra's extensive coastline spans 720 km and is divided into six maritime districts: Mumbai, Thane, Raigad, Sindhudurg, Ratnagiri and Palghar. The continental shelf in this region covers an area of 1, 11,512 sq km.

In terms of contribution, the mechanised sector plays a substantial role, accounting for 98.78% of the total marine fish landings in Maharashtra, while the non-mechanised sector contributes only 1.22%. Maharashtra has 17,362 fishing craft in total, 13,016 of which are mechanised. Greater Mumbai, within Maharashtra, boasts 2,849 trawlers among its fleet. Trawl nets are the most commonly used fishing gear in the region, representing 54.7% of the total. Trawlers have played a significant role in advancing India's overall marine fishery (Srinath, 2003). Indian marine fisheries boast 167,957 fishing crafts, with 53% being non-motorised, 24% motorised and 23% mechanised. Since the 1990s, the catch of many commercially important fish species in Maharashtra has declined, primarily due to overfishing (Deshmukh, 2013). The bycatch issue in multispecies fisheries is a significant concern in tropical trawl fisheries. The ecological impact of fishing gear on the marine environment has been a significant concern in managing ocean resources (Bijukumar and Deepthi, 2006). It has also been recognised as a prominent human-induced physical disturbance to continental shelves worldwide, leading to ecosystem degradation. Therefore, the main objective of this study is to examine the fish assemblages found in trawl catches along the Mumbai coast. Our goal is to learn more about the ecological effects of the trawling operations in the area by examining the catch composition.

Materials and methods

Study area

Experimental fishing was undertaken onboard the research vessel MFV NARMADA (IV) of ICAR-Central Institute of Fisheries Education, Mumbai (ICAR-CIFE) from September 2019 to March 2020. The study encompassed 14 haul observations, which were conducted in a single-day experimental trawler operation within the Mumbai coastal waters (Fig. 1). The primary objectives of this study were to investigate fish catch compositions, characterised by bycatch, and examine monthly variations. Water depth was determined by employing a graded nylon rope coupled with an iron sinker. Throughout the study, a cod-end with a 30 mm mesh size was towed at a speed varying from 1.5 to 2.5 knots. This was accomplished using a trawl-net featuring a 35 m head-rope, a 40 m foot-rope, and mesh dimensions of Wing-200 mm, Belly-150 mm, Overhang-200 and 100 mm, with throat dimensions of 75 and 35 mm. Partially frozen fish samples were collected and transported to the laboratory. Further details regarding the design and structure of the trawl are presented in Fig. 2 and 3.

Sample identification

Numerous resources were utilised to identify each species in the unsorted samples up to the species level. The FAO identification sheet specific to fishing area 51, as well as works by Jayaram (2002), Nelson (2004), Raje (2007) and Talwar and Kacker (1984), were used. Furthermore, sources such as FishBase (Froese and

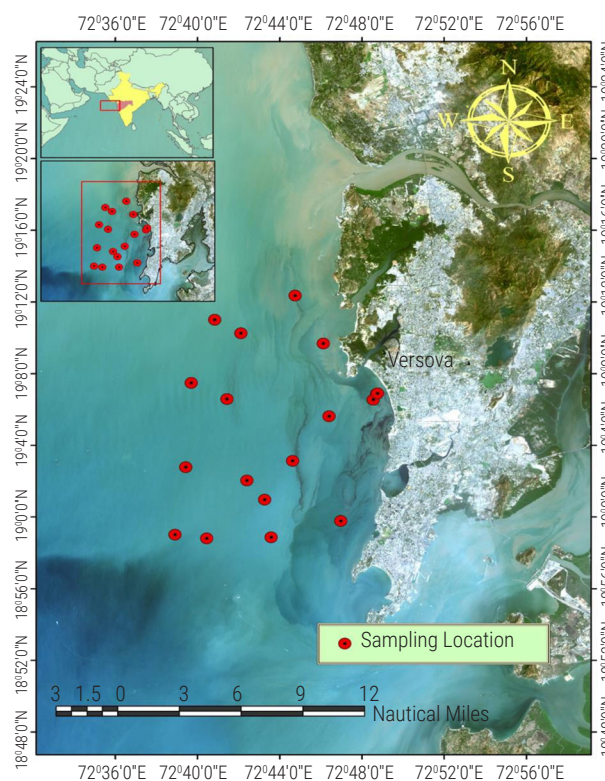


Fig. 1. Study area location, Mumbai coastal waters, India

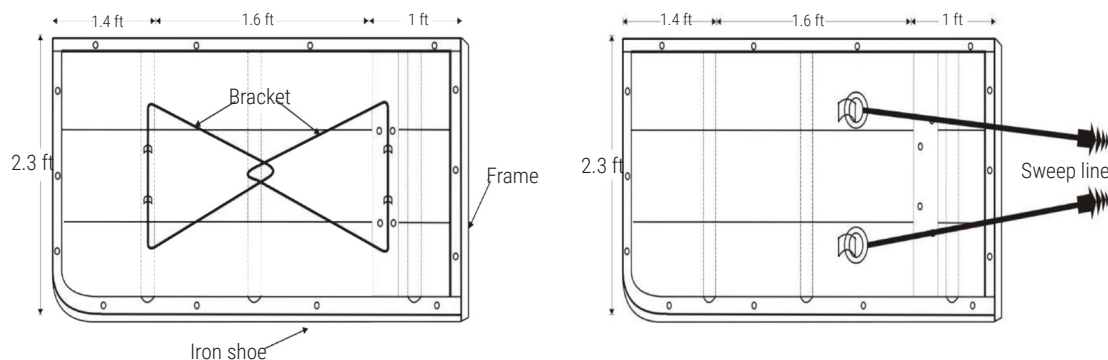


Fig. 2. Design of otter board

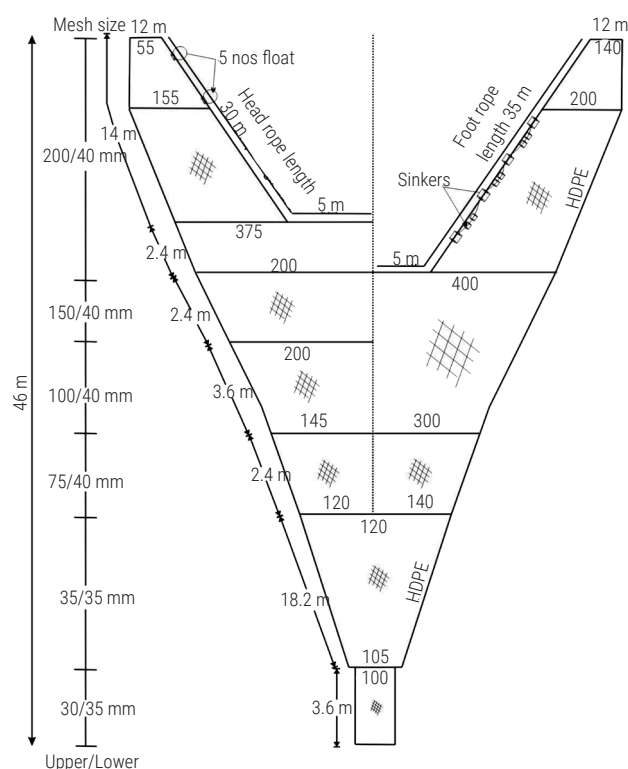


Fig. 3. Design of trawl used in experimental fishing along the Mumbai coastal waters

Pauly, 2018) and the World Register of Marine Species (Horton *et al.*, 2018) were used to confirm the authenticity of the species names. The study ensured accurate identification of the species in the samples, enhancing the reliability and validity of the research findings by employing these references and databases.

Species composition

A comprehensive total of 127 species were recorded over the study period. Ninety-two of these were finfish, which included 40 families, 14 orders and 68 genera. Furthermore, 34 species (25 genera, 9 orders and 27 families) were categorised as shellfish. With

51 species representing 74% of the ichthyofaunal diversity, the order Perciformes demonstrated significance in terms of fish diversity. Tetraodontiformes had five species (7%) and Clupeiformes had thirteen (19%). Decapoda accounted for 21 species (81%), whereas Neogastropoda 5 species (19%) of shellfish. 88 species of finfish, 12 species of shrimp, 9 species of gastropods, 5 species of crabs, 3 species of cephalopods, 3 species of stomatopods, 4 species of elasmobranchs, 1 species of lobster, 1 species of hermit crab and 1 species of jellyfish were among the species encountered.

Catch per unit effort

To calculate the proportional weight of each species or group in the overall trawl hauls, each species in the samples was individually weighed, following the procedure described by Reed *et al.* (2017). The following equation was applied to estimate the total weight of each species within a haul:

$$W_{spi} = f_{spi} \times W_i$$

Here, W_{spi} represents the total weight of species sp in the i^{th} haul, f_{spi} is the fraction of species sp in the i^{th} sample and W_i is the total weight of all fishes in the i^{th} trawl haul.

The catch per unit effort (CPUE) was computed in kilograms per hour (kg h^{-1}) to standardise the total weight of each species in a haul. The CPUE for each species within a haul was calculated by dividing the total weight in kilograms of that species by the time required to complete the tow, as expressed in the following equation:

$$CPUE_{spi} = W_{spi} / h_i$$

In the provided equation, $CPUE_{spi}$ stands for the catch per unit effort for a specific species in the i^{th} haul, while h_i represents the duration in hours during which the trawl was towed in that particular haul. We calculated the abundance of the target catch, bycatch and discard for each haul to examine the data in more detail. These calculations facilitated an evaluation of the quantities within these categories concerning the fishing effort. Subsequently, the CPUE data collected from the samples were averaged to yield monthly CPUE data. Averaging CPUE values over a specific time frame provided a more comprehensive view of the catch per unit effort for the species of interest. Moreover, we computed abundance statistics to gauge the overall abundance levels of the target catch, bycatch and discard. These statistics offered further insights into the relative quantities of these categories. By employing these calculations and statistical analyses, our study aimed to assess catch rates, abundances and associated trends for the different

catch categories, ultimately contributing to a better understanding of fishing dynamics and resource utilisation.

Spatio-temporal variation in catch

Cluster analysis was employed to explore the seasonal relationships among bycatch species. The species names were represented by the first two letters of the genus and the species to create a clear dendrogram plot. To mitigate the influence of high-abundance species, the abundance data for bycatch was normalised through square root transformation, following the methods of Velip and Rivonker (2015) and Behera *et al.* (2017). The monthly data was categorised into three groups: post-monsoon (September–November), winter (December–February) and early-summer (March) to examine spatial distribution in the catch. Additionally, to analyse the distribution patterns of species rates, the data was grouped into five clusters based on different depth strata, specifically 6–9, 9–12, 12–15, 15–18 and 18–21 m. ArcGIS (version 10.8), MS Excel and PRIMER software (version 6) were used for creating maps and graphs.

The evaluation of fish diversity indices in the study area involved the use of multiple biodiversity indices, namely Shannon–Weinner index (H'), Simpson diversity index (1- D), Margalef's species richness index (Dmg), Menhinick's index (Dmn) and Species evenness Pielou's index (J). These indices were computed utilising PRIMER version 6 (Clarke and Warwick, 2001).

Results

Species-wise catch composition and CPUE

In the comprehensive analysis, the catch composition is depicted in Fig. 4 and the list of identified species is presented in Table 1. Sciaenids accounted for the largest portion, contributing 20% to the total catch. They were followed by squilla (13%), elasmobranchs (11%), flatfishes and ribbonfish (10%) and Golden anchovy (9%). Shrimps, hermit crabs and shellfish collectively made up 4% of the catch, while pomfret and miscellaneous species accounted for 3%.

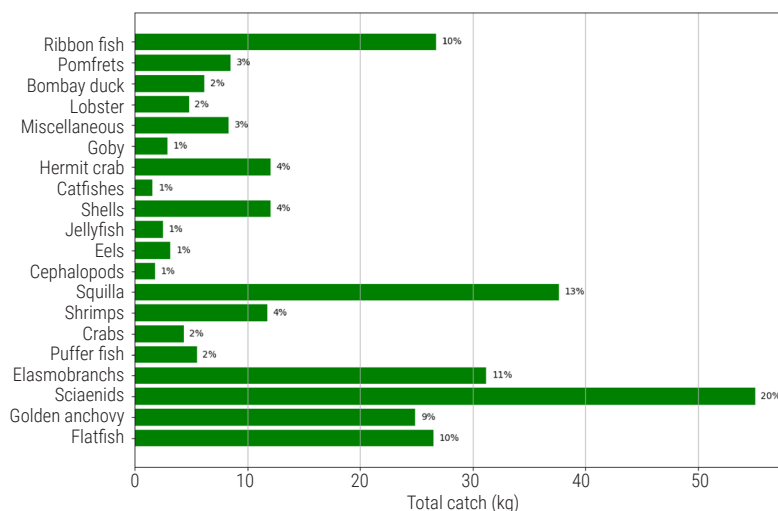


Fig. 4. Overall trawl catch composition along the Mumbai coastal waters

Pufferfish, Bombay duck, crabs, and lobster collectively represented 2% of the catch. Eels, Goby, jellyfish, cephalopods and catfishes each contributed 1% to the total catch. In the monthly contribution of commercial catch (Fig. 5), the major species/groups were sciaenids, elasmobranchs, ribbonfish, shrimps, golden anchovy, pomfrets, Bombay duck, lobster, crabs, flatfishes, cephalopods and catfishes. Sciaenids (6.65 kg h^{-1}) and elasmobranchs (5 kg h^{-1}) were the most abundant species in March, with ribbonfish (3.67 kg h^{-1}) in November, shrimp (3.33 kg h^{-1}) in September, golden anchovy (2.0 kg h^{-1}) in October and pomfrets (3.1 kg h^{-1}) in March. Besides these seven species/groups, the species/group that was most abundant were Bombay duck, lobster, crabs, flatfish, cephalopods and catfish.

In group-wise monthly contribution of discarded catch (Fig. 6), the major species/groups recorded were sciaenids, squilla, elasmobranchs, flatfishes, golden anchovy, hermit crab, ribbonfish, shells, cephalopods, eels, jellyfish, catfishes, goby and miscellaneous. During October, sciaenids (13.86 kg h^{-1}) and Squilla (8.48 kg h^{-1}) were recorded more, followed by elasmobranchs (5 kg h^{-1}) in January and flatfishes (7 kg h^{-1}) in October and November.

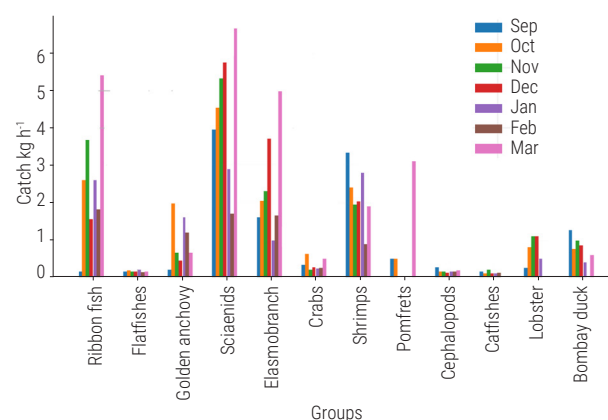


Fig. 5. Group-wise monthly contribution to commercial catch

Table 1. List of identified fish species along the Mumbai coastal waters in trawling operation

Order: Anguilliformes	Family: Congridae	1	<i>Uroconger lepturus</i> (Richardson, 1845)
	Family: Muraenesocidae	2	<i>Muraenesox bagio</i> (Hamilton, 1822)
		3	<i>Muraenesox cinereus</i> (Forsskal, 1775)
	Family: Ophichthidae	4	<i>Pisodonophis boro</i> (Hamilton, 1822)
Order: Aulopiformes	Family: Synodontidae	5	<i>Harpadon nehereus</i> (Hamilton, 1822)
		6	<i>Saurida tumbil</i> (Bloch, 1795)
		7	<i>Saurida undosquamis</i> (Richardson, 1848)
Order: Beloniformes	Family: Belonidae	8	<i>Strongylura strongylura</i> (vanHasselt, 1823)
Order: Clupeiformes	Family: Chirocentridae	9	<i>Chirocentrus dorab</i> (Forsskal, 1775)
		10	<i>Anodontostoma chacunda</i> (Hamilton, 1822)
		11	<i>Escualosa thoracata</i> (Valenciennes, 1847)
		12	<i>Nematalosa nasus</i> (Bloch, 1795)
	Family: Clupeidae	13	<i>Sardinella longiceps</i> Valenciennes, 1847
		14	<i>Tenualosa toli</i> (Valenciennes, 1847)
	Family: Engraulidae	15	<i>Coilia dussumieri</i> Valenciennes, 1848
		16	<i>Thryssa dussumieri</i> (Valenciennes, 1848)
		17	<i>Thryssa hamiltonii</i> Gray, 1835
	Family: Pristigasteridae	18	<i>Thryssa setirostris</i> (Broussonet, 1782)
		19	<i>Thryssa mystax</i> (Bloch & Schneider, 1801)
		20	<i>Opisthopterus tardoore</i> (Cuvier, 1829)
		21	<i>Pellona ditchela</i> Valenciennes, 1847
Order: Gobiiformes	Family: Oxudercidae	22	<i>Odontamblyopus roseus</i> (Valenciennes, 1837)
		23	<i>Trypauchen vagina</i> (Bloch & Schneider, 1801)
Order: Mugiliformes	Family: Mugilidae	24	<i>Mugil cephalus</i> Linnaeus, 1758
Order: Perciformes	Family: Carangidae	25	<i>Alepes kleinii</i> (Bloch, 1793)
		26	<i>Atropus atropus</i> (Bloch & Schneider, 1801)
		27	<i>Alepes djedaba</i> (Forsskal, 1775)
		28	<i>Caranx para</i> Cuvier, 1833
		29	<i>Caranx Hebert</i> (Bennett, 1830)
		30	<i>Caranx ignobilis</i> (Forsskal, 1775)
		31	<i>Carangoides ferdau</i> (Forsskal, 1775)
		32	<i>Decapterus russelli</i> (Rüppell, 1830)
		33	<i>Megalaspis cordyla</i> (Linnaeus, 1758)
		34	<i>Parastromateus niger</i> (Bloch, 1795)
		35	<i>Seriolina nigrofasciata</i> (Rüppell, 1829)
		36	<i>Scomberoides tol</i> (Cuvier, 1832)
		37	<i>Drepane punctata</i> (Linnaeus, 1758)
	Family: Drepaneidae	38	<i>Leiognathus equulus</i> (Forsskal, 1775)
	Family: Gerreidae	39	<i>Gerres filamentosus</i> Cuvier, 1829
	Family: Leiognathidae	40	<i>Leiognathus equulus</i> (Forsskal, 1775)
	Family: Lactariidae	41	<i>Lactarius lactarius</i> (Bloch & Schneider, 1801)
	Family: Mullidae	42	<i>Upeneus vittatus</i> (Forsskal, 1775)
		43	<i>Upeneus moluccensis</i> (Bleeker, 1855)
	Family: Nemipteridae	44	<i>Nemipterus bipunctatus</i> (Valenciennes, 1830)
		45	<i>Nemipterus japonicus</i> (Bloch, 1791)
	Family: Polynemidae	46	<i>Filimnus heptadactyla</i> (Cuvier, 1829)
		47	<i>Eleutheronema tetradactylum</i> (Shaw, 1804)
	Family: Priacanthidae	48	<i>Priacanthus hamrur</i> (Forsskal, 1775)
	Family: Sciaenidae	49	<i>Johnius macrorhynchus</i> (Lal Mohan, 1976)
		50	<i>Johnius sina</i> (Cuvier, 1830)
		51	<i>Johnius glaucus</i> (Day, 1876)

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Order: Perciformes	Family: Sciaenidae	52	<i>Johnius belangerii</i> (Cuvier, 1830)
		53	<i>Johnius borneensis</i> (Bleeker, 1851)
		54	<i>Johnius elongatus</i> LalMohan, 1976
		55	<i>Nibea maculata</i> (Bloch & Schneider, 1801)
		56	<i>Johnius dussumieri</i> (Cuvier, 1830)
		57	<i>Otolithoides biauritus</i> (Cantor, 1849)
		58	<i>Otolithes cuvieri</i> Trewavas, 1974
		59	<i>Protonibea diacanthus</i> (Lacepede, 1802)
	Family: Scatophagidae	60	<i>Scatophagus argus</i> (Linnaeus, 1766)
	Family: Scombridae	61	<i>Scomberomorus guttatus</i> (Bloch & Schneider, 1801)
		62	<i>Rastrelliger kanagurta</i> (Cuvier, 1816)
	Family: Serranidae	63	<i>Epinephelus diacanthus</i> (Valenciennes, 1828)
	Family: Sillaginidae	64	<i>Sillago sihama</i> (Forsskal, 1775)
	Family: Sparidae	65	<i>Acanthopagrus arabicus</i> Iwatsuki, 2013
	Family: Sphyracidae	66	<i>Sphyracna jello</i> Cuvier, 1829
		67	<i>Sphyracna forsteri</i> Cuvier, 1829
		68	<i>Sphyracna obtusata</i> Cuvier, 1829
	Family: Stromateidae	69	<i>Pampus argenteus</i> (Euphrasen, 1788)
		70	<i>Pampus chinensis</i> (Euphrasen, 1788)
	Family: Terapontidae	71	<i>Terapon theraps</i> Cuvier, 1829
		72	<i>Terapon jarbua</i> (Forsskal, 1775)
	Family: Trichiuridae	73	<i>Lepturacanthus savala</i> (Cuvier, 1829)
		74	<i>Eupleurogrammus muticus</i> (Gray, 1831)
		75	<i>Trichiurus lepturus</i> Linnaeus, 1758
Order: Pleuronectiformes	Family: Cynoglossidae	76	<i>Cynoglossus arel</i> (Bloch & Schneider, 1801)
		77	<i>Cynoglossus dubius</i> Day, 1873
		78	<i>Cynoglossus macrostomus</i> Norman, 1928
	Family: Soleidae	79	<i>Solea elongata</i> Day, 1877
Order: Siluriformes	Family: Ariidae	80	<i>Osteogeneiosus militaris</i> (Linnaeus, 1758)
		81	<i>Plicofollis dussumieri</i> (Valenciennes, 1840)
Order: Scorpaeniformes	Family: Platycephalidae	82	<i>Grammolites suppositus</i> (Troschel, 1840)
		83	<i>Kumococius rodericensis</i> (Cuvier, 1829)
Order: Tetraodontiformes	Family: Tetraodontidae	84	<i>Lagocephalus inermis</i> (Temminck & Schlegel, 1850)
		85	<i>Lagocephalus guentheri</i> Miranda Ribeiro, 1915
		86	<i>Takifugu oblongus</i> (Bloch, 1786)
		87	<i>Lagocephalus lunaris</i> (Bloch & Schneider, 1801)
	Family: Triacanthidae	88	<i>Triacanthus biaculeatus</i> (Bloch, 1786)
Elasmobranchs			
Order: Orecto	Family: Carcharhinidae	89	<i>Scoliodon laticaudus</i> Muller & Henle, 1838
Carcharhiniformes	Family: Sphyrnidae	90	<i>Sphyrna lewini</i> (Griffith & Smith, 1834)
Order: Myliobatiformes	Family: Dasyatidae	91	<i>Brevitrygon imbricata</i> (Bloch & Schneider, 1801)
Order: Orectolobiformes	Family: Hemiscylliidae	92	<i>Chiloscyllium arabicum</i> Gubanov, 1980
Crustaceans (shrimps, lobsters and crabs)			
Shrimps			
Order: Decapoda	Family: Penaeidae	93	<i>Parapenaeopsis sculptilis</i> (Heller, 1862)
		94	<i>Parapenaeopsis stylifera</i> (H. Milne Edwards, 1837)
		95	<i>Metapenaeus affinis</i> (H. Milne Edwards, 1837)
		96	<i>Metapenaeus brevicornis</i> (H. Milne Edwards, 1837)
		97	<i>Metapenaeus dobsoni</i> (Miers, 1878)
		98	<i>Metapenaeus monoceros</i> (Fabricius, 1798)
		99	<i>Penaeus japonicus</i> (Bate, 1888)
		100	<i>Penaeus merguensis</i> (De Man, 1888)
		101	<i>Penaeus monodon</i> Fabricius, 1798

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	Family: Sergestidae	102	<i>Acetes indicus</i> H. Milne Edwards, 1830
	Family: Hippolytidae	103	<i>Exhippolysmata ensirostris</i> (Kemp, 1914)
	Family: Solenoceridae	104	<i>Solenocera crassicornis</i> (H. Milne Edwards, 1837)
Lobsters			
Order: Decapoda	Family: Palinuridae	105	<i>Panulirus polyphagus</i> (Herbst, 1793)
Crabs			
Order: Decapoda	Family: Portunidae	106	<i>Portunus pelagicus</i> (Linnaeus, 1758)
		107	<i>Portunus sanguinolentus</i> (Herbst, 1783)
		108	<i>Charybdis feriatus</i> (Linnaeus, 1758)
		109	<i>Charybdis lucifera</i> (Fabricius, 1798)
		110	<i>Charybdis callianassa</i> (Herbst, 1789)
Hermit crab			
Order: Decapoda	Family: Diogenidae	111	<i>Diogenes alias</i> (McLaughlin & Holthuis, 2001)
Mantis shrimps			
Order: Stomatopoda	Family: Squillidae	112	<i>Miyakella nepa</i> (Latreille, 1828)
		113	<i>Oratosquilla perpersa</i> (Kemp, 1911)
		114	<i>Harpisquilla raphidea</i> (Fabricius, 1798)
Molluscs			
Class: Cephalopoda			
Order: Octopoda	Family: Octopodidae	115	<i>Octopus vulgaris</i> (Cuvier, 1797)
Order: Teuthida	Family: Loliginidae	116	<i>Urotheuthis (Photololigo) duvaucelii</i> (d'Obigny [in Ferussac & d'Obigny], 1835)
Order: Sephida	Family: Sepiidae	117	<i>Sepiella inermis</i> (Van Hasselt, 1835)
Class: Gastropoda			
Order: Neogastropoda	Family: Muricidae	118	<i>Indothais lacera</i> (Born, 1778)
		119	<i>Rapana rapiformis</i> (Born, 1778)
	Family: Babyloniidae	120	<i>Babylonia spirata</i> (Linnaeus, 1758)
	Family: Pisanidae	121	<i>Cantharus spiralis</i> Gray, 1839
	Family: Clavatulidae	122	<i>Turricula javana</i> (Linnaeus, 1767)
Order: Litorinimorpha	Family: Ranellidae	123	<i>Gyrineum natator</i> (Roding, 1798)
	Family: Rostellariidae	124	<i>Tibia curta</i> (G. B. Sowerby, 1842)
	Family: Bursidae	125	<i>Bufonaria crumena</i> (Link, 1807)
	Family: Naticidae	126	<i>Tanea lineata</i> (Roding, 1798)
Phylum: Cnidaria			
Class: Scyphozoa		127	Jellyfish

The monthly distribution of commercial and discarded catch revealed that the highest number of species of 99, was recorded in September, while the lowest number, 36 species, was recorded in January (Fig. 7). In terms of monthly contributions from major catch groups, sciaenids showed the highest catch at 13.86 kg h⁻¹ in October, followed by Stomatopoda at 8.48 kg h⁻¹ also in October. On the other hand, the lowest catch for sciaenids, 1.65 kg h⁻¹, was observed in January, followed by Stomatopoda with 0.94 kg h⁻¹ in December (Fig. 8). The total catch was categorised into three distinct groups. The first category was the target catch, which primarily consisted of shrimps. The second category was the non-target catch, which included the portion of the catch that had good market value and demand but did not consist of shrimps. Lastly, the third category was the discarded catch, which encompassed all the low-value fishes and juveniles that were not commercially significant. Upon analysis, it was observed that the contribution of the target catch was relatively low compared to the non-target and discards. The month-wise and overall catch contributions indicated that discards had the highest proportion, accounting for 59% of the total catch. The non-target catch followed with a contribution of 34%, while the target catch had the lowest contribution at 7%.

These findings are depicted in Figs. 9 and 11, providing a visual representation of the relative proportions of each catch category. The average per day discards from experimental trawling varied from 4.5 to 24.75 kg h⁻¹ and the catch generated by commercial trawling varied from 4.1 to 12.2 kg h⁻¹. The maximum commercial

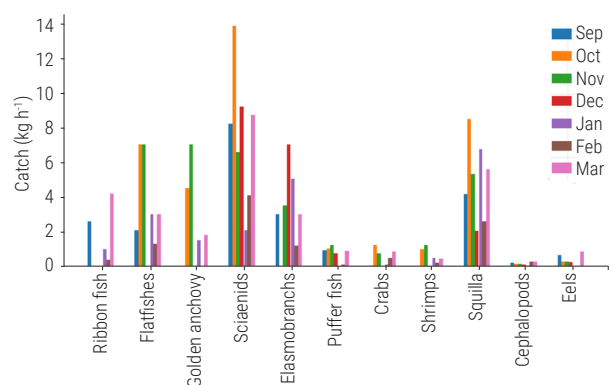


Fig. 6. Group-wise monthly contribution to discards

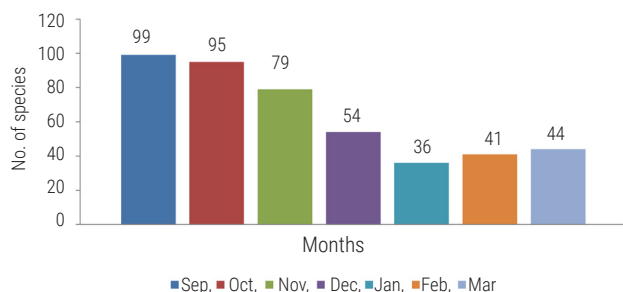


Fig. 7. Monthly distributions of commercial and discard details along Mumbai coastal waters

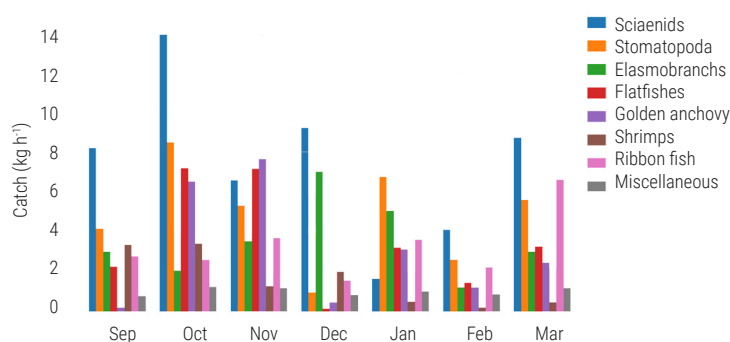


Fig. 8. Monthly contributions of major groups of catch along Mumbai coastal waters

catch was observed in February and minimum in January. Likewise, discarded catch was maximum in October and minimum in March.

Cluster analysis

The study utilised, hierarchical cluster analysis to examine the similarities in species composition and abundance patterns over time. A dendrogram was constructed, illustrating the distinct grouping and similarity in species composition and abundance across months and seasons to provide a visual representation of the clustering results. The comprehensive cluster analysis highlighted a notable similarity in both species composition and abundance (97.61%) between September and October 2019, contrasting with the comparatively lower similarity observed between November and December 2019 (92.38%) (Fig. 10). The dendrogram provided a clear visualisation, delineating distinct groupings that underscored the diverse similarities in species composition and abundance across the different months. Fig. 10 shows the hierarchical clustering results, which were obtained using the group average linkage method between months throughout the study period. The overall cluster analysis revealed that the highest similarity in species composition and abundance occurred between adjacent months.

Spatial distribution of catches

The most prevalent fish species during the study period are listed in (Table 1, Fig. 12a, b and c) along with the species abbreviations applied in the dendrogram and cluster analysis. Bycatch exhibited significant variation across the seasons, with the lowest occurring during winter and the highest observed in the post-monsoon period.

This analysis allowed for the identification of clustering patterns and similarities in the bycatch composition across different seasons. During post-monsoon, species association (Fig. 12a) consisted of *Uroconger lepturus*, *Muraenesox bagio*, *Pisodonophis boro*, *Harpadon nehereus*, *Priacanthus hamrur*, *Sepiella inermis*, *Cynoglossus arel*, *Megalaspis cordyla*, *Lagocephalus guentheri*, *Thryssa dussumieri*, *T. hamiltonii*, *Odontamblyopus roseus*, *Scomberomorus guttatus*, *Lactarius lactarius*, *Protonibea diacanthus*, *Plicofollis dussumieri*, *Rastrelliger kanagurta*, *Sphyaena jello* and *S. forsteri*. During the post-monsoon season, the highest similarity was observed between *Sphyaena jello* and *P. dussumieri*, *R. kanagurta* and *S. forsteri*, as well as *Megalaspis cordyla* and *Cynoglossus arel*. Conversely, the lowest similarity was found between *T. dussumieri* and *Johnius glaucus*.

During winter species association included (Fig. 12b) *M. cinereus*, *Terapon jarbua*, *Lepturacanthus savala*, *Eupleurogrammus muticus*, *Otolithes cuvieri* and *Nematalosa nasus*. The highest similarity was identified between *H. nehereus* and *Pisodonophis boro*, as well as *T. jarbua* and *R. kanagurta*. In contrast, the lowest similarity was found between *O. cuvieri* and *Otolithoides biauritus*.

During early-summer, species association included (Fig. 12c) *Trichiurus lepturus*, *Johnius glaucus*, *Saurida undosquamis*, *Strongylura strongylura*, *Upeneus vittatus*, *S. longiceps*, *Tenualosa toli*, *Coilia dussumieri*, *Urotheuthis (Photololigo) duvaucelii*, *Scatophagus argus*, *Johnius dussumieri*, *O. biauritus*, *Nibea maculata*, *Chirocentrus dorab* and *Pampus argenteus*. The highest similarity was noted

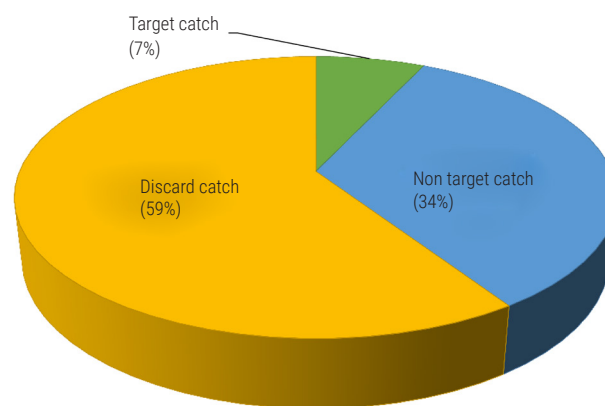


Fig. 9. Percentage contributions of target catch, non-target catch and discard

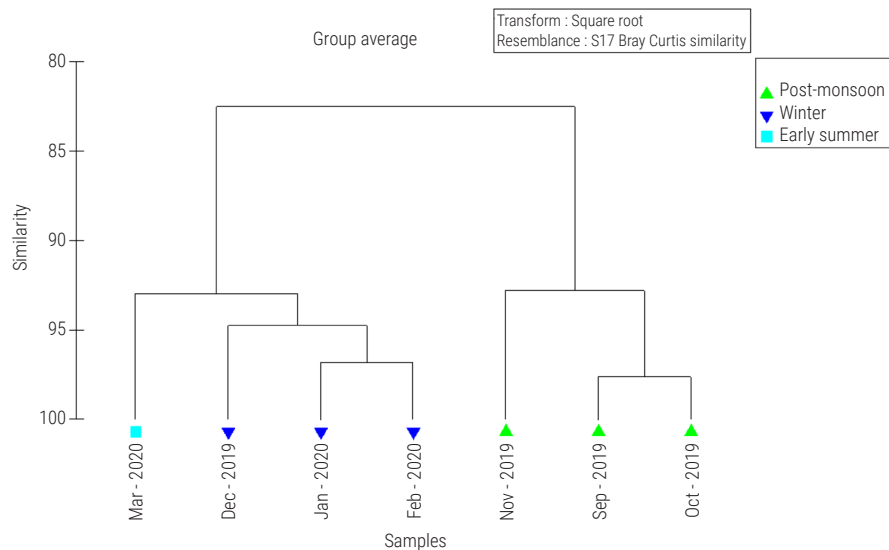


Fig. 10. Hierarchical clustering month-wise observed from September 2019 to March 2020. (Transform: square root; Resemblance: S17 Bray Curtis similarity). The dendrogram drawn revealed the separate grouping similarity in species composition and abundance of different months and seasons

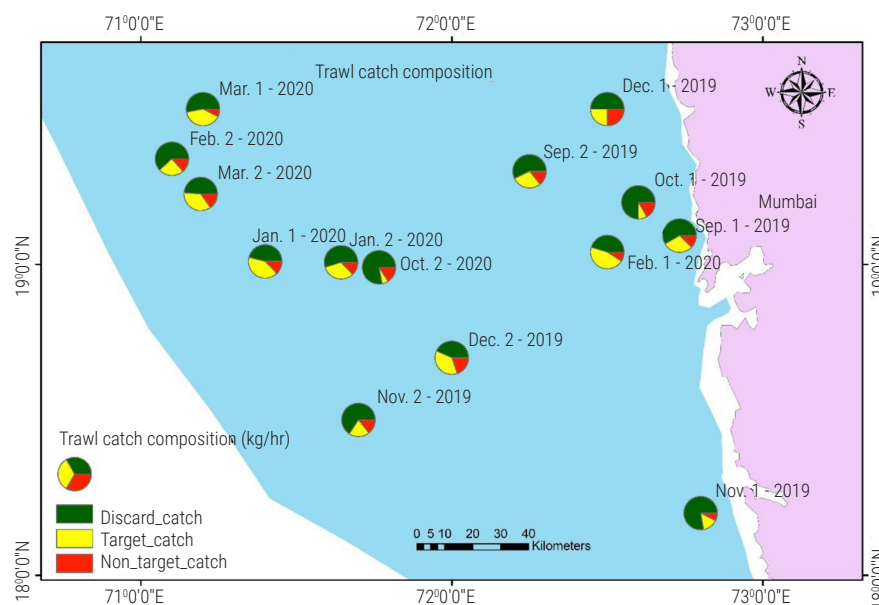


Fig. 11. Trawl catch composition: monthly discard, target and non-target catch (kg h^{-1}) from Sept1_2019 to March2_2020 (No. 1 and 2 indicate fishing operation)

between *P. hamrur* and *H. nehereus*, *P. diacanthus* and *O. cuvieri* and *E. muticus* and *L. savala*. Conversely, the lowest similarity was observed between *J. glaucus* and *P. argenteus*.

When considering the monthly variations in species diversity indices, the overall mean (H') value along Mumbai coastal waters was 2.61 ± 0.10 . The highest (H') value was observed in January (2.96), while the lowest was in October (2.27). Similarly, the overall mean (1-D) value was 0.92 ± 0.01 , with the highest value occurring in January (0.94) and the lowest in October (0.89). The overall mean (J) value was estimated to be 0.95 ± 0.02 , with the highest value in November (0.97) and the lowest in March (0.85). For (Dmn), the

overall mean value was 3.47 ± 0.16 . The highest (Dmn) value was recorded in November (4.26), while the lowest was in October (3.01). Similarly, the overall mean (Dmg) value was 4.78 ± 0.32 , with the highest value in January (6.14) and the lowest in October (3.75) (Table 2 and Fig. 13).

The distribution of commercial and discarded catch species varied with depth. The highest number of species was 66, which was recorded in the depth range of 15-18 m. This was followed by 60 species in the depth range of 12-15 m, 55 species in the depth range of 9-12 m, 41 species in the depth range of 18-21 m and the lowest number of species, 36 in total, recorded in the depth range of 6-9 m.

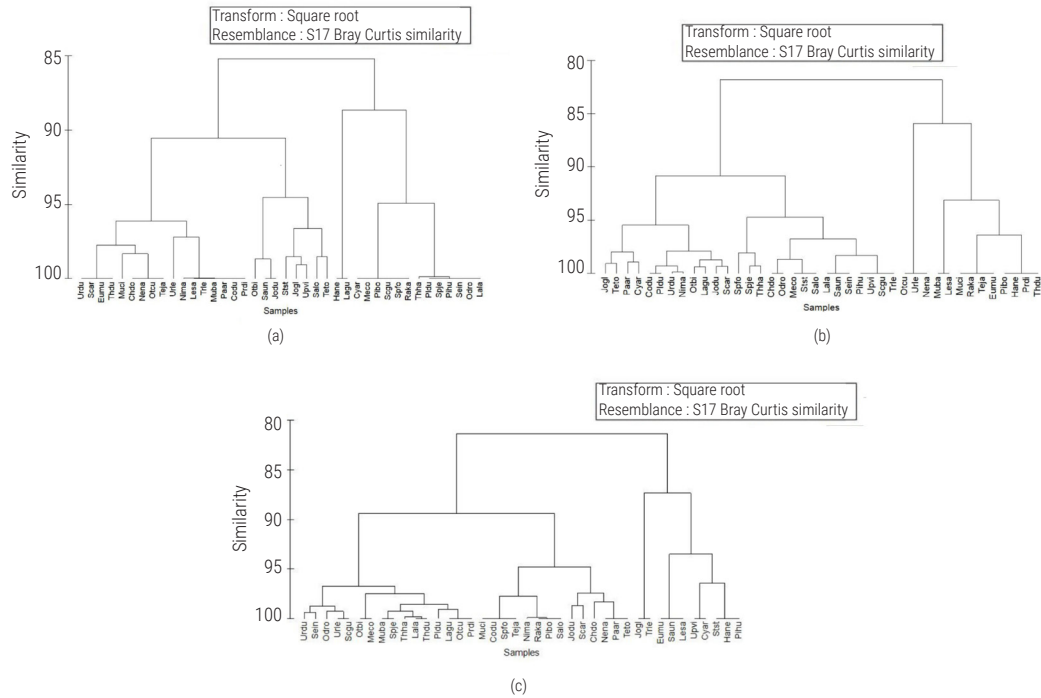


Fig. 12. Season-wise bycatch showed in dendrogram clustering (Transform: square root; Resemblance: S17 Bray Curtis similarity). (a) Post-monsoon, (b) winter and (c) early summer

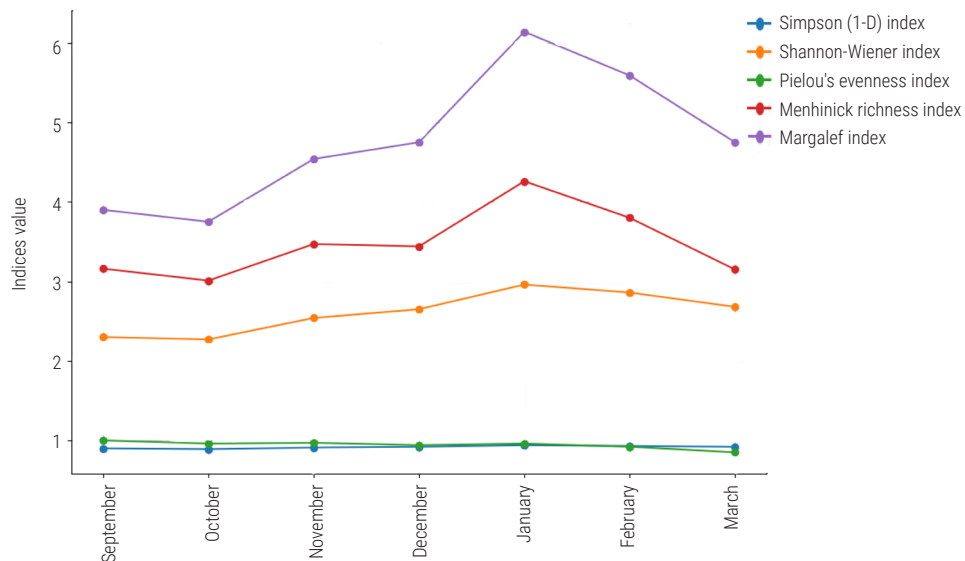


Fig. 13. Month-wise diversity indices along the Mumbai coastal waters

Table 2. Monthly variations in different indices based on species abundance

Indices	September	October	November	December	January	February	March	Mean±SE
Individuals	10	11	14	19	22	25	29	*
Simpson (1-D) index	0.9	0.89	0.91	0.92	0.94	0.93	0.92	0.92±0.01
Shannon-Wiener index	2.3	2.27	2.54	2.65	2.96	2.86	2.68	2.61±0.10
Pielou's Evenness index (J)	1	0.96	0.97	0.94	0.96	0.92	0.85	0.95±0.02
Menhinick richness index (Dmn)	3.16	3.01	3.47	3.44	4.26	3.8	3.15	3.47±0.16
Margalef index (Dmg)	3.9	3.75	4.54	4.75	6.14	5.59	4.75	4.78±0.32

SE= Standard error

Discussion

The results of this study, indicated that the proportion of discarded catch exceeded that of the commercial catch and align with findings from prior studies conducted along the Indian coast. Many researchers have made attempts to study the catch composition of trawl nets operated along the Indian coast (Rao and Dorairaj 1968; George *et al.*, 1981; Pillai *et al.*, 1983; Gordon 1991; Sehara and Karbhari, 1991; Joel and Ebenezzer, 1996; Pravin *et al.*, 1998; Kurup *et al.*, 2003; Kumar and Deepthi, 2006; Boopendranath, 2008; Dineshbabu, 2013; Soykan *et al.*, 2016; Behera *et al.*, 2017; Samanta *et al.*, 2018; Devi *et al.*, 2019; Kodeeswaran *et al.*, 2020; Kumar *et al.*, 2020; Azeez *et al.*, 2021). Rao and Dorairaj (1968) revealed fish catch data with the help of the GOI trawling vessels of Goa. Approximately 80% of the catches consisted of small sciaenids (52.79%), catfishes (14.91%) and elasmobranchs (12.55%). Quality fish species like false trevally and pomfrets constituted 7.82 and 1.69%, respectively, while shrimps contributed 1.43% of the catches. Notably, the catch composition of single-day and multi-day trawlers in Kerala was examined in a study conducted by Hassan and Sathiadhas in 2009 and the marine fish landings in Greater Mumbai from 1998 to 2004 were investigated by Annam and Augustine (2005). Dineshbabu (2013) observed that the catches of the west coast of India during 2008-2012 comprised threadfin breams (13.4%), ribbonfishes (10.7%), penaeid shrimps (9.6%), sciaenids (6.6%), squids (6.1%), cuttlefish (5.5%), lizard fishes (4.3%), scads (3.6%), non-penaeid shrimps (3.4%) and Indian mackerel (2.6%). The cephalopods emerged as a significant group, with squids and cuttlefishes contributing 12%.

Soykan *et al.* (2016) revealed the catch composition of the bottom trawl fishery of Sigacik Bay, eastern Mediterranean. The reported landings included 84 species, consisting of 47 bony fishes, 9 cartilaginous fishes, 10 cephalopods, 13 crustaceans, 4 echinoderms and 1 porifera species. In the Mumbai trawl catch during 2016-17, *O. cuvieri* (24%) was the dominant species, followed by *Arius maculatus* (16%), *L. savala* (15%), penaeid shrimps (10%), *U. duvaucelii* (8%), *C. macrostomus* and *M. cordyla* (each 6%) and *H. nehereus*, *T. dussumieri* and *P. argenteus* (each 5%) (Kharatmol *et al.*, 2018). Kumar *et al.* (2015) documented marine ichthyofaunal biodiversity in the trawling grounds off the Mangalore coast, reporting 97 species belonging to 72 genera, 50 families and 15 orders during the study period. Samanta *et al.* (2018) reported bycatch and discards from a single day shrimp trawling off the Mumbai coast. According to their findings, sciaenids comprised the majority of the total capture (35%), followed by sharks and rays (10%), anchovies (10%), shrimps (8%), Bombay duck (6%) and other demersal species. The mean monthly bycatch varied from 11.82 to 20.65 kg h⁻¹. Behera *et al.* (2017) examined 53 trawl hauls of a commercial shrimp trawler from December 2013 to December 2014 to determine the by-catch composition, catch rates of key species, and seasonal fluctuation. Devi *et al.* (2019) studied the catch composition along the Mumbai coast in Maharashtra. Their findings indicated that the highest fish landings by multi-day trawlers occurred in September and October, marking the peak seasons. In contrast, the lean periods for Versova, SSD and NFW were observed in August, December and May, respectively. Rizvi *et al.* (2010) documented the species composition *T. lepturus* (78.8%), *L. savala* (21.8%) and *E. muticus* (3.4%) on the Mumbai coast. The analysis of bycatches and discards in marine capture fisheries in Uran (Raigad), Navi Mumbai, Maharashtra, was

carried out by Prabhakar (2011). This study reported 101 species obtained from the capture and discards of marine fish in the Karanja and Mora districts of Uran (Raigad), Navi Mumbai, Maharashtra. Gokce *et al.* (2016) studied the catch composition biodiversity of Mersin Bay from 2009 to 2013, a north-eastern Mediterranean fishing ground for demersal trawls. The most abundant species observed were *Mullus barbatus* and *Equulites klunzingeri* among 135 species. Elasmobranchs were observed in trawl catch along Chennai during 2002-06, sharks (12.8%), rays (74.1%) and guitar fishes (13.1%) (Mohanraj *et al.*, 2009). Hassan and Sathidas (2009) studied trawl landings at the Neendakara landing centre, where the catch was dominated by threadfin breams (31%), followed by high-priced cuttlefish (24%), ribbon fishes (12%) and deep-sea shrimps, accompanied by small fish, (11%). Five different depth strata were selected viz. 6-9, 9-12, 12-15, 15-18 and 18-21 m to study the variation in species distribution. The highest number of species, of 66, were found in depths between 15-18 m and the lowest number, 36, between 6-9 m. A similar observation was reported by Bhendekar *et al.* (2019) based on the depth-wise distribution of species, with the highest number of 70 species recorded in a depth range of 15-19 m followed by 65 species in 20-24 m and 64 species in 10-14 m.

The average values of biodiversity indices in the studied region were as follows: Shannon-Weinner index (H') = 2.61 ± 0.10 , Simpson diversity index ($1-D$) = 0.92 ± 0.01 , Margalef's species richness index (Dmg) = 4.78 ± 0.32 , Menhinick's index (Dmn) = 3.47 ± 0.16 and species evenness Pielou's index (J) = 0.95 ± 0.02 . Comparing these values with previous studies, Bhendekar *et al.* (2019) reported Shannon-Weinner index (H) values ranging from 1.42 to 1.63 along the Mumbai coast, while Kodeeswaran *et al.* (2020) found values between 4.53 and 5.63 from the south-east coast of India. Clarke and Warwick (2001) suggested a Shannon index (H) higher than 3.5 indicating a healthy and diverse ecosystem. Singh *et al.* (2023) documented a value of 3.67 for H' along the south Konkan coast. In comparison, the average H' value of 2.61 in this study suggests a relatively diverse coastal ecosystem in the Mumbai coastal waters of Maharashtra. The Simpson index ($1-D$) had an average value of 0.92, with the highest in January and the lowest in October. Pielou's evenness index (J) had an average value of 0.95, with the lowest value in March and the highest in November. Bhendekar *et al.* (2019) and Kodeeswaran *et al.* (2020) reported J values ranging from 0.82 to 0.90 and 0.77 to 0.81, respectively. Pielou's evenness index (J) is commonly used to express how evenly individuals are distributed among the species. It is strongly affected by species richness. The average value of evenness (J') recorded was 0.95, with the lowest during March and the highest in November. Bhendekar *et al.* (2019) also reported the highest value of J (0.90) during December. However, the results showed that the abundance of fish species was distributed evenly in the studied region. Singh *et al.* (2023) reported value of evenness (J') from 0.88 to 0.92, with the lowest during February and the highest in December. Margalef's species richness index (Dmg) provides a simple measure of biodiversity by counting the number of species in a given area. The average value of (Dmg) recorded was 0.95, with the lowest during October and the highest in November. However, it is important to note that Margalef's index may deviate from the actual diversity value to some extent because it does not properly account for evenness and depends on sample size. Menhinick's index (Dmn) measure species richness and its value depends on the number of

species and individuals. The average value (D_{mn}) recorded was 4.78, with the lowest during October and the highest in January. Menhinick's index can be influenced by species richness and environmental conditions. A higher value suggests a larger number of species and lesser individuals.

In the study, the overall cluster analysis revealed the highest similarity in species composition and abundance between adjacent months. This indicates that species composition and abundance exhibited similar patterns during consecutive months. This finding align with the results reported along the Mangaluru coast on the south-west coast of India (Kumar *et al.*, 2020). The study identified the most prevalent fish species during different seasons. Bycatch showed significant variation, with the lowest occurrence in winter and the highest in the post-monsoon period. Clustering analysis revealed patterns and similarities in the bycatch composition. Season-wise bycatch was maximum during the post-monsoon and similar results were reported along the north-western Indian coast (Azeez *et al.*, 2021). In the post-monsoon season, several species were found to be associated. In winter, a different set of species showed associations, and in early summer, another species group was observed. The results indicated the dominant group of fish species in the north-western Indian coast (Sreekanth *et al.*, 2016; Bhendekar *et al.*, 2019; Azeez *et al.*, 2021). Both trophic interaction and habitat sharing are responsible for the seasonal relationships of different fish species in bycatches (Velip and Rivonker, 2015; Behera *et al.*, 2017; Duarte *et al.*, 2022). The catch rate generally declines during the winter and summer when fishing extends into deeper waters. According to Samanta *et al.* (2018) and Velip and Rivonker (2015), environmental factors and lunar cycles also affect the spatiotemporal variability of trawl bycatch. Fishing becomes rather productive after the ban period or post-monsoon months (August to November). It is typically concentrated in inshore regions and fishermen report better catch rates (Ghosh *et al.*, 2009; CMFRI, 2020) higher bycatch and discard rates. These findings provide valuable insights into the diverse species composition within the study area, contributing to our understanding of the local marine ecosystem. Overall, the studied region exhibits high species diversity and supports multispecies fisheries. It is recommended to prevent overexploitation of juvenile fish stocks, by enforcing mesh size regulations and area or seasonal closures for the conservation and sustainable management of fisheries along the Mumbai coastal waters.

In recent decades, fish catches along the Mumbai coastal waters have experienced a decline, primarily due to factors such as rapid coastal growth, urbanisation, habitat loss, overfishing and an increase in the number of boats. The current study aims to comprehensively examine discard, non-targeted catch and targeted catch in this area. It highlights the decreasing abundance of fish catches resulting from both natural processes and human activities. To address this issue and mitigate its impact, it is essential to improve gear selectivity and ensure the long-term sustainability of non-target species affected by trawling through the implementation of a long-term bycatch monitoring process. These observations highlight the significant presence of discard and non-targeted catch in the overall catch composition. Understanding these catch categories and their contributions is crucial for effective fisheries management and conservation efforts. This research contributes to understanding species-level patterns within the fish community in a dynamic marine environment. It aids in the development of an effective management system for their conservation.

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