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Analysis of bycatches from mid-water trawl fishery targeting ribbonfish *Trichiurus lepturus* on the north-west coast of India

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Abstract

Commercial trawl fisheries are closely associated with bycatch and discards and it significantly affects the non-target resources, biodiversity, ecosystem function and habitat. The present study analysed bycatch based on data obtained from commercially operated multiday midwater trawlers operating off the north-west coast of India during August 2017-December 2019. The data revealed that bycatch and discards constituted about 53 and 6% respectively of the trawl catch. Mid-water trawl bycatch comprised 92 Teleosts, 8 Cephalopods, 12 Crustaceans and 11 Elasmobranch species. The bycatch is mainly comprised of cuttlefishes, squids, threadfin breams, sciaenids, bullseye and lizardfishes. Further, 93.68% of the bycatch consisted of commercially important fish, hence it was retained in the vessel. The bycatch rate was high in September (72.81±37.44 kg h^{-1}) whereas, for discards, it was in August (16.25±10.84 kg h^{-1}).

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Introduction

The north-west coast of India (NWCI) includes two coastal provinces, Gujarat and Maharashtra and the region is known for the high-intensity mechanised fishing and 48.81% (17,195 units) of trawlers in India are operated here (MOA and CMFRI, 2012). NWCI accounted for 28.91% (2,347 km) of the coastline and 33% (2. 96 lakh km^2) of the continental shelf area of India (MOA and CMFRI, 2012). A wider continental shelf in this region provided extensive fishing grounds and resulted in a greater abundance of fishery resources and this region contributed 32.1% (1.14 million t) of total marine fish landed through capture fisheries (CMFRI, 2019). The trawlers operated from the NWCI target shrimps, demersal fishes, cephalopods and ribbonfishes. Therefore, they carry several trawl net variants onboard to exploit these resources depending on the season and fishing grounds (Azeez *et al.*, 2021). Cephalopods and ribbonfishes live in column waters, hence trawlers targeting these resources are known as midwater trawlers or semi-pelagic trawlers.

Bycatch is an integral component in trawl fisheries. They are retained (when fish have market value) or discarded (when they comprise juveniles or fishes that have poor market value) (Alverson *et al.*, 1994; Hall, 1996). Bycatch and discard components from commercial crustacean and demersal fish trawlers vary in different regions of the Indian coast (George *et al.*, 1981; Dineshbabu *et al.*, 2012a; Velip and Rivonker, 2015; Mahesh *et al.*, 2017; Samanta *et al.*, 2018). It significantly affects the non-target resources, biodiversity, ecosystem function and habitat (Pauly *et al.* 2001; Bijukumar and Deepthi, 2009; Bhagirathan *et al.*, 2014; Dineshbabu *et al.*, 2016; Mahesh *et al.*, 2019) Further, juvenile bycatch poses a serious ecological impact, affecting the long-term sustainability of the resources through growth overfishing of the stock leading to reduced economic returns (Dineshbabu and Radhakrishnan, 2009; Dineshbabu *et al.*, 2014; Mahesh *et al.*, 2019). India has a large fleet of trawlers operating in its coastal waters with a significant proportion targeting the mid-water shoaling fishes such as the ribbonfishes, horse mackerel, mackerels, cephalopods and threadfin breams. Therefore, regular monitoring of bycatch and discards with details of its spatial and seasonal variability is important for framing management policies. In this context, an attempt was made to analyse the bycatches from mid-water trawl that targeted the ribbonfish *Trichiurus lepturus* in the NWCI.

Materials and methods

Sample collection

Onboard bycatch samples (geo-tagged) were collected from randomly selected three multiday mid-water trawlers operating along NWCI and targeting ribbonfish from August 2017 to December 2019. Samples comprised 834 haul observations and sampling during June and July was not possible due to the annual fishing ban for the mechanised sector during these months in this region. The head rope of mid-water trawl nets measured 65-70 m and the foot rope 70-75 m. The mesh size of the cod end ranged from 20-35 mm. A total of 830 hauls with an average duration of 3 h 21 m and towing speed of 3.7 knots were performed at depths between 20 and 450 m. All operations were made only during the day. The data collected from the fishing vessels was restricted to the fishing coordinate-wise catch information provided in the prescribed schedule. The schedule included information on latitude and longitude of fishing ground, date, time, depth of fishing, trawling speed, total catch in the haul as well as quantity of bycatch and discards (Dineshbabu *et al.,* 2012b). A representative sample (about 5 kg bycatch and 2 kg discard) of the catch was collected from each haul made by the vessels. Samples were drawn strictly before sorting the catch and before discards were thrown overboard, to ensure a true representation of the catch. These samples were tagged and kept in an insulated box with ice till the completion of the voyage and brought to the laboratory for further analysis (species identification and verification of logbook catch data). Larger fauna such as adult carangids, scombroids and elasmobranchs were counted and weighed onboard to minimise sampling error (Reed *et al.,* 2017).

Species identification

The sample from individual hauls was examined separately and categorised as teleosts, elasmobranchs, cephalopods and crustaceans. They were identified as the lowest possible taxa using the conventional taxonomic methods using meristic counts and morphometric measurements (Fischer and Bianchi, 1984; Jereb and Roper, 2005, 2010; Dash *et al.,* 2013).

Data analysis

The total weight of each species in a haul was normalised using catch per unit effort (CPUE) in kilogram per hour (kg h^{-1}) of the fishing operation. CPUE of species was calculated for each haul by total weight in a kilogram of each species divided by the time taken to complete a tow. Similarly, abundances of target catch, bycatch and discard were calculated for each haul. Subsequently, CPUE data from samples were averaged to obtain monthly CPUE data for each species or group.

The data were grouped depth-wise into the following five clusters based on fishing grounds as 0-50, 50-100, 100-150, 150-200 m and more than 200 m depth stratum to analyse spatial changes of bycatch and discard. Kruskal-Wallis test carried for the depth-wise significant differences in CPUEs (bycatch and discard) (Reed *et al.,* 2017). Spatial patterns of species in the bycatch were analysed using cluster analysis to understand the spatial cluster among the locations. The data for each species were aggregated into 30' × 30' grid block catch in the study region. The CPUE for each species in a grid block was averaged to provide the average CPUE for a species in the grid block using equation 1 (Azeez *et al.,* 2023a).

$$\overline{\mathrm{CPUE}}_{spg} = \frac{\mathrm{CPUE}_{spt}}{N_g} \quad \text{.........(1)}$$

where $\overline{\mathrm{CPUE}}_{spg}$ is the average catch of a species (*sp*) in a grid block (*g*), $CPUE_{spt}$ is CPUE of species (*sp*) in total (*t*), N_g is number of trawling observed in a grid block (*g*).

Grid blocks with less than 8 (1%) trawl observations were excluded unless the grid block formed part of a group of contiguous grid blocks. To limit the analysis to species composition as opposed to catch rate, the values were converted to proportions of the average total CPUE of the grid block. The proportions were normalised using square root transformation to down-weight the impact of highly abundant species. A lower triangular matrix was calculated using the Bray-Curtis similarity coefficient (Bray and Curtis, 1957) to determine dissimilarity among the grid blocks. Cluster analysis was carried out by group-average linking to construct a dendrogram for each analysis using the 'vegan' package in R (Oksanen *et al.,* 2019). The dendrogram was used to identify the species, contributing to similarity within groups and dissimilarity among groups.

Results and discussion

Species composition

Mid-water trawl bycatch comprised teleosts (92 species) which formed 62.09% of the total bycatch by weight, followed by cephalopods (8 species), crustaceans (12 species) and elasmobranchs (11 species; Table 1 and Fig. 1). The number of species associated with the mid-water trawl fishery was only one-third (123 species) as compared to the bottom trawl fishery in the region, due to the selective operation for target resources such as ribbonfish (Fennessy and Groeneveld, 1997; Bijukumar and Deepthi, 2009; Velip and Rivonker, 2015; Samanta *et al.,* 2018). However, the species diversity of mid-water trawls operated in tropical waters was higher than those operated in temperate waters (Hofstede and Dickey-Collas, 2006; Borges *et al.,* 2008; Reed *et al.*, 2017; Sabet *et al.,* 2018). In Iran, 62 species of bycatch were observed in fleet targeting ribbonfish (Sabet *et al.,* 2018), while South African midwater trawl fishery targeting adult horse mackerel had 87 species of bycatch (Reed *et al.*, 2017). One hundered and thirty species of bycatch species were recorded in Dutch pelagic freezer-trawler operating in Mauritanian waters that targeted sardines, pilchard, chub mackerel and Cunene horse mackerel (Hofstede and Dickey-Collas, 2006). The bycatch from mid-water trawler shared 53.36% of the total catch and consisted mainly of cuttlefish, squid, threadfin bream, sciaenid, bullseye and lizardfish. The species with the highest annual average catches in the bycatch and discards are given in Fig. 2 and 3. The results revealed that 93.68% of bycatches were commercially important fishes, hence

Table 1. List of bycatch species shared in biomass (%) and number (%) and their taxonomic order and families from mid-water trawler operating in NWCI

Order	Family	Species	Biomass %	Number %
Teleosts				
Anguilliformes	Muraenesocidae	*Congresox talabonoides*	1.44	0.74
Aulopiformes	Synodontidae	*Harpadon nehereus*	0.13	0.20
		Saurida tumbil	3.93	6.02
		S. undosquamis	0.06	0.10
Beloniformes	Exocoetidae	*Hirundichthys coromandelensis*	<0.01	<0.01
	Hemiramphidae	*Hemiramphus archipelagicus*	0.01	0.01
		H. far	<0.01	<0.01
Carangiformes	Carangidae	*Alepes djedaba*	0.01	0.01
		Atropus atropos	0.54	0.41
		Carangoides malabaricus	<0.01	<0.01
		Caranx para	0.92	0.71
		C. sexfasciatus	1.20	0.91
		Decapterus russelli	0.66	1.00
		Megalapsis cordyla	1.37	1.57
		Parastromateus niger	0.23	0.18
		Scomberoides commersonnianus	0.61	0.20
		S. tala	0.05	0.04
		S. tol	0.16	0.12
		Selaroides leptolepis	0.03	0.04
Clupeiformes	Chirocentridae	*Chirocentrus dorab*	0.94	0.52
		C. nudus	0.54	0.33
	Clupeidae	*Anodontostoma chacunda*	0.01	0.01
		Hilsa kelee	0.01	<0.01
		Sardinella albella	0.02	0.03
		S. fimbriata	0.01	0.02
		S. gibbosa	0.01	0.01
		Sardinella spp.	0.32	0.36
		Tenualosa ilisha	0.15	0.09
		T. toli	0.07	0.05
	Dussumieriidae	*Dussumieria acuta*	0.56	0.65
	Engraulidae	*Coilia dussumieri*	0.01	0.03
		Thryssa dussumieri	0.27	0.42
		T. mystax	0.01	0.02
	Pristigasteridae	*Pellona ditchela*	0.12	0.11
		Ilisha megaloptera	1.21	0.73
		Opisthopterus tardoore	0.39	0.44
Mugiliformes	Mugilidae	*Mugil cephalus*	0.02	0.02
Perciformes	Apogonidae	*Nectamia savayensis*	0.22	0.53
		Pristiapogon fraenatus	0.13	0.18
	Coryphaenidae	*Coryphaena hippurus*	0.68	0.10
	Gerreidae	*Gerres filamentosus*	0.01	0.01
	Haemulidae	*Diagramma pictum*	<0.01	<0.01
		Pomadasys argenteus	0.01	0.01
	Lactariidae	*Lactarius lactarius*	0.16	0.25
	Lethrinidae	*Lethrinus ornatus*	0.83	0.76
	Lutjanidae	*Lutjanus bohar*	0.05	0.03
		L. gibbus	0.05	0.04
		L. johnii	0.02	0.01
		Pristipomoides filamentosus	0.02	0.01

Contd.....

	Menidae	*Mene maculata*	0.29	0.44
	Mullidae	*Upeneus sulphureus*	0.91	0.91
		U. vittatus	0.25	0.26
	Nemipteridae	*Nemipterus japonicus*	6.80	4.59
		Nemipterus randalli	1.70	1.22
	Polynemidae	*Polynemus heptadactylus*	0.02	0.02
		P. indicus	0.08	0.09
		P. tetradactylus	0.17	0.18
	Priacanthidae	*Priacanthus hamrur*	5.12	3.18
	Rachycentridae	*Rachycentron canadum*	0.05	0.03
	Sciaenidae	*Johnieops sina*	0.12	0.13
		Johnius belangerii	0.06	0.06
		J. glaucus	3.91	4.08
		Otolithes cuvieri	6.58	6.04
		O. ruber	0.27	0.27
		Otolithoides biauritus	0.32	0.30
	Scombridae	*Auxis thazard*	0.17	0.13
		Euthynnus affinis	0.03	0.01
		Thunnus tonggol	0.01	<0.01
		Rastrelliger kanagurta	0.85	0.89
		Scomberomorus commerson	0.56	0.45
		S. guttatus	0.91	0.95
	Serranidae	*Epinephelus chabaudi*	0.87	0.80
		E. diacanthus	3.65	2.54
		E. faveatus	0.33	0.24
		E. latifasciatus	0.55	0.45
	Sparidae	*Acanthopagrus berda*	0.14	0.11
	Sphyraenidae	*Sphyraena jello*	1.53	2.34
		S. obtusata	0.55	0.85
		S. putnamae	0.01	0.01
	Stromateidae	*Pampus argenteus*	0.97	0.70
	Terapontidae	*Terapon theraps*	<0.01	<0.01
	Trichiuridae	*Eupleurogrammus muticus*	0.01	0.01
		Lepturacanthus savala	0.48	0.34
Pleuronectiformes	Psettodidae	*Psettodes erumei*	0.24	0.25
	Soleidae	*Zebrias quagga*	0.27	0.41
Scorpaeniformes	Platycephalidae	*Platycephalus indicus*	1.41	1.29
Siluriformes	Ariidae	*Osteogeneiosus militaris*	0.13	0.11
		Plicofollis dussumieri	0.58	0.60
		P. tenuispinis	1.19	1.09
Tetraodontiformes	Balistidae	*Odonus niger*	0.16	0.25
	Monacanthidae	*Aluterus monoceros*	1.37	0.57
	Tetraodontidae	*Lagocephalus inermis*	0.40	0.61
Elasmobranchs				
Carcharhiniformes	Carcharhinidae	*Carcharhinus falciformis*	0.06	<0.01
		C. limbatus	0.05	<0.01
		Rhizoprionodon acutus	0.06	<0.01
		Scoliodon laticaudus	0.09	0.06
	Sphyrnidae	*Sphyrna lewini*	0.01	<0.01
Lamniformes	Alopiidae	*Alopias pelagicus*	0.06	0.00
	Lamnidae	*Isurus oxyrinchus*	0.05	0.00
Myliobatiformes	Dasyatidae	*Dasyatis zugei*	0.07	0.02
		Himantura imbricata	0.06	0.01
		Himantura imbricata	0.06	0.01

Contd.....

Rhinopristiformes	Rhinobatidae	*Rhinobatos annandalei*	0.06	0.03
	Rhinopteridae	*Rhinoptera javanica*	<0.01	<0.01
Cephalopods				
Myopsida	Loliginidae	*Uroteuthis (Photololigo) duvaucelii*	9.78	8.64
		U. singhalensis	3.75	3.91
Octopoda	Octopodidae	*Amphioctopus neglectus*	0.34	0.26
		Octopus membranaceus	1.38	1.05
Sepiida	Sepiidae	*Sepia elliptica*	6.92	10.59
		S. kobiensis	2.60	2.98
		S. pharaonis	6.55	4.30
		Sepiella inermis	4.44	6.79
Crustaceans				
Decapoda	Palinuridae	*Panulirus polyphagus*	0.14	0.11
	Penaeidae	*Metapenaeus affinis*	0.21	0.70
		M. monoceros	0.15	0.69
		Parapenaeopsis sculptilis	0.01	0.06
		P. stylifera	0.36	1.63
		Penaeus monodon	0.11	0.25
		P. merguiensis	0.04	0.20
		P. penicillatus	0.01	0.06
		P. semisulcatus	0.08	0.38
	Portunidae	*Portunus pelagicus*	0.04	0.07
		P. sanguinolentus	<0.01	<0.01
	Salenoceridae	*Solenocera crassicornis*	0.30	1.36

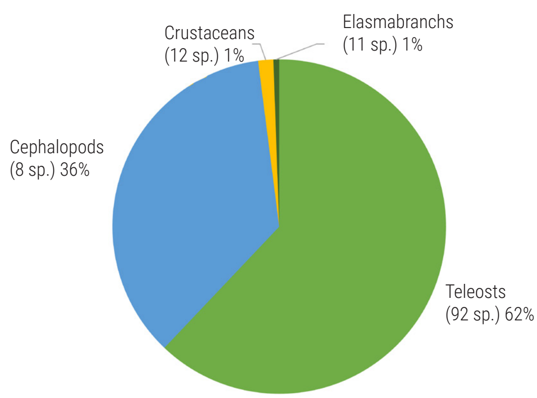

Fig. 1. Share of bycatch taxonomic groups in mid-water trawler operating in NWCI

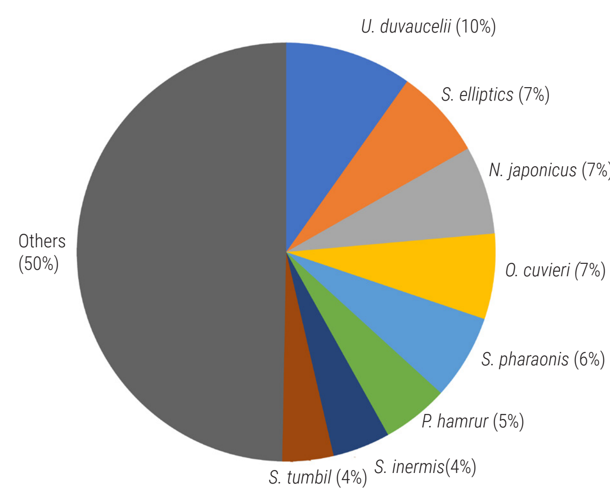

Fig. 2. Share of major species in bycatch of mid-water trawler operating in NWCI

it was retained in the vessel, but the low value and juvenile fishes were discarded back to sea. Discards shared 6.32% of the total catch (in terms of quantity) and comprised 64 species belonging to 29 families (Table 2). The most common discards were juveniles of lizardfishes, threadfin breams, flatheads, sciaenid, ribbonfish and eels, which together formed about 53.09% of the total discards (in terms of quantity) (Fig. 3).

Monthly trends of abundance

Seasonal migration of fishes aids in feeding and reproduction as well as to avoid extreme environmental conditions (Northcote, 1978; Stobutzki *et al.*, 2001; Olsson *et al.*, 2006). Previous studies indicated seasonal variations of bycatch rates in the tropical trawl fisheries (Tonks *et al.*, 2008; Dineshbabu *et al.*,2010; Velip and Rivonker, 2015; Reed *et al.*, 2017). Similarly, the monthly catch rate varied for ribbonfish (targeted), bycatch and discards (Fig. 4-6) and bycatch and discards were closely associated with ribbonfish catch. The lowest monthly CPUE (22.24±14.32 kg h^{-1}) for ribbonfish was observed in April and the highest average CPUE (59.75±23.57 kg h^{-1}) was in August. For the bycatch, the lowest monthly CPUE (28.96±11.24 kg h^{-1}) was observed in April and the highest CPUE (72.81±37.44 kg h^{-1}) in September whereas, for discards, the lowest CPUE (4.52±2.21 kg h^{-1}) was in November and the highest CPUE (16.25±10.84 kg h^{-1}) in August. The higher catch rates during post-monsoon months (August to November) could be attributed to

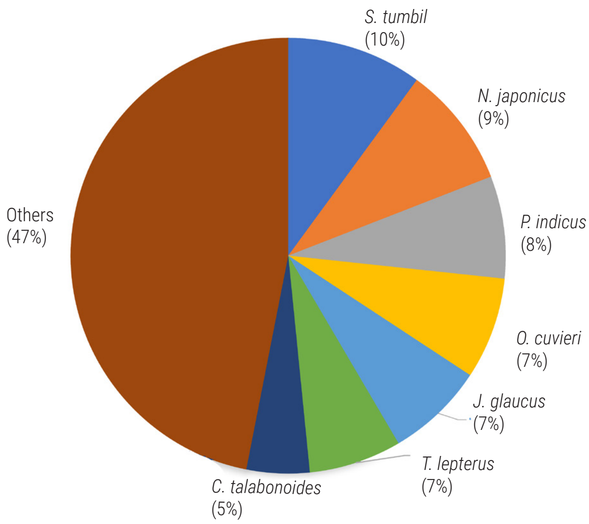

Fig. 3. Share of major species in discard of mid-water trawler operating in NWCI

the intense fishery concentrated within the inshore areas (CMFRI, 2019; Ghosh *et al.,* 2009). The fishery expanded to deeper areas in the winter months (December to February), when most of the commercially important fishes breed in the NWCI (CMFRI, 2019; Dineshbabu, 2013) or undertake partial breeding migration (Chapman *et al.,* 2012), leading to a general reduction in catch rates during winter and summer periods.

Spatial patterns

Spatial distribution of catches revealed that bycatch (χ^2 = 14.91, p<0.01, df = 4) and discards (χ^2 = 29.26, p<0.001, df = 4) were significantly different at various depth stratum in NWCI. The lowest average bycatch (46.26±15.47 kg h^{-1}) and discards (2.23±1.9 kg h^{-1}) were observed from deeper (offshore) waters *i.e.*, beyond 200 m depth whereas the highest average bycatch (68.00±23.45 kg h^{-1}) and discards (11.26±7.59 kg h^{-1}) were observed from inshore waters within 50 m depth (Fig. 7).

The aggregation of bycatch data by grid blocks yielded data for 63 grid blocks. The exclusion of grid blocks with less than 8 trawls,

Table 2. Percentage of species discarded from mid-water trawlers operating along NWCI

Species	Biomass (%)	No. (%)	Species	Biomass (%)	No. (%)
Osteogeneiosus militaris	0.26	0.10	*Aluterus monoceros*	0.67	0.40
Pristiapogon fraenatus	1.44	0.51	*Upeneus sulphureus*	1.29	1.54
Nectamia savayensis	2.43	1.52	*U. vittatus*	0.32	0.38
Odonus niger	1.46	0.87	*Congresox talabonoides*	4.67	2.78
Megalaspsis cordyla	0.69	0.41	*Nemipterus japonicus*	9.03	10.74
Decapterus russelli	0.64	0.54	*N. randalli*	1.63	1.94
Atropus atropos	0.53	0.32	*Platycephalus indicus*	7.60	4.52
Parastromateus niger	0.17	0.21	*Polynemus tetradactylus*	0.84	1.00
Selaroides leptolepis	0.18	0.21	*P. heptadactylus*	0.09	0.05
Carangoides malabaricus	0.02	0.02	*Priacanthus hamrur*	3.28	1.95
Chirocentrus nudus	0.95	0.38	*Rhinobatos annandalei*	0.18	0.10
C. dorab	0.48	0.19	*Otolithes cuvieri*	7.56	8.99
Ilisha megaloptera	1.47	0.87	*O. ruber*	1.57	1.87
Dussumieria acuta	1.17	1.39	*Otolithoides biauritus*	0.43	0.51
Opisthopterus tardoore	1.67	1.99	*Johnius glaucus*	7.29	8.67
Thryssa dussumieri	1.17	1.39	*Johnieops sina*	0.50	0.59
T. mystax	0.09	0.11	*Sepia inermis*	2.00	2.38
Tenualosa ilisha	0.29	0.17	*Epinephelus diacanthus*	1.98	1.18
T. toli	0.26	0.31	*E. latifasciatus*	1.64	0.97
Pellona ditchela	0.22	0.26	*E. faveatus*	0.57	0.34
Sardinella albella	0.12	0.15	*Zebrias quagga*	0.22	0.26
S. fimbriata	0.07	0.08	*Acanthopagrus berda*	0.53	0.32
S. gibbose	0.06	0.03	*Sphyraena jello*	2.40	2.85
Sardinella spp.	1.47	1.74	*S. putnamae*	1.58	4.71
Coilia dussumeri	0.15	0.18	*Harpadon nehereus*	0.96	1.14
Gerres filamentosus	0.04	0.05	*Saurida tumbil*	10.06	11.97
Pomadasys argenteus	0.05	0.03	*S. undosquamis*	0.31	0.37
Diagramma pictum	0.04	0.02	*Terapon theraps*	0.01	0.04
Lactarius lactarius	0.93	1.11	*Lagocephalus inermis*	0.52	3.12
Uroteuthis (Photololigo) duvaucelii	1.17	1.39	*Trichiurus lepturus*	6.88	4.09
U. singhalensis	0.61	0.72	*Lepturacanthus savala*	1.18	0.70
Mene maculata	1.85	2.20	*Eupleurogrammus muticus*	0.07	0.04

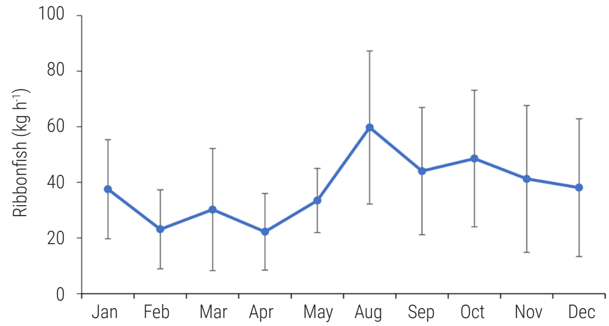

Fig. 4. Monthly mean CPUE of ribbonfish from mid-water trawlers operating in NWCI. Error lines represent standard deviation

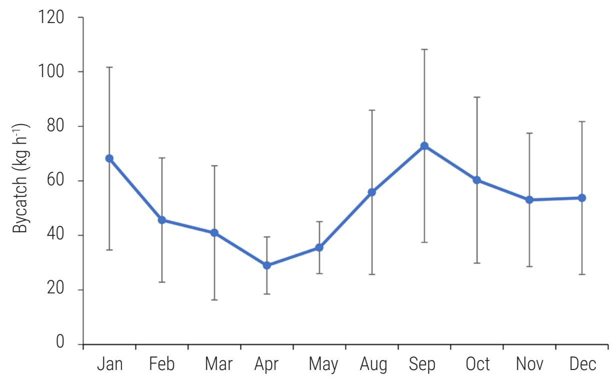

Fig. 5. Monthly mean CPUE of bycatch from mid-water trawlers operating in NWCI. Error lines represent standard deviation

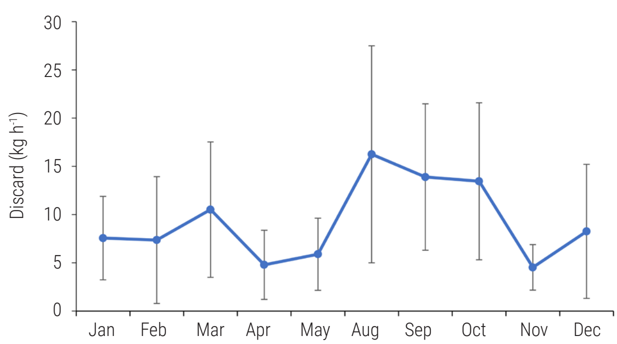

Fig. 6. Monthly mean CPUE of discards from mid-water trawlers operating in NWCI. Error lines represent standard deviation

reduced it to 42 grid blocks for spatial analysis. Cluster analysis identified five groups of grid blocks, namely A, B, C, D and E in NWCI (Fig. 8). Group B, C and E showed only one set of continuous blocks, while A and D had two sets of continuous blocks (Fig. 9). Group A separated from other groups and was located off Gujarat waters (above 20°30'N) irrespective of bathymetric barriers whereas other groups were located below 20°30'N. Group B was located in inshore waters near 50 m contours, Group D was located between 50 and 100 m depth whereas Group C and E were located in offshore waters around 100 to 200 m depth.

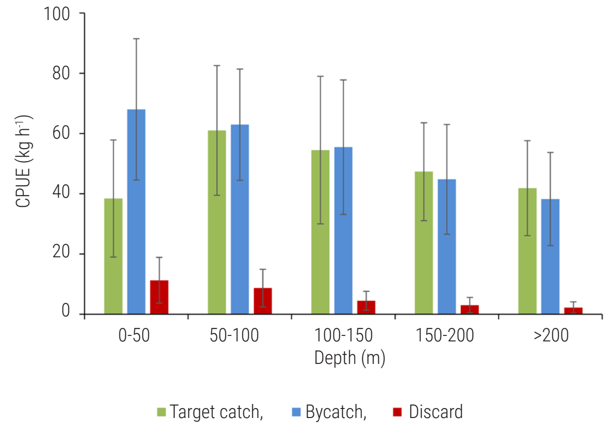

Fig. 7. Bathymetric variation of mean CPUE for target catch, bycatch and discards from mid-water trawlers operating in NWCI

The high proportion of bycatch and discards in the coastal waters was due to the reason that the mid-water trawl net has large wings to enhance vertical mouth opening to target the pelagic shoaling fishes and when such nets operate in inshore waters, the distance between foot rope and bottom of the sea becomes minimum. Further, the use of a smaller cod end mesh size (25-35 mm) less than that recommended (40 mm) for the ribbonfish (Rajeswari *et al.,* 2013) and high species diversity in the inshore waters leads to a high rate of bycatch and discards in tropical waters (EJF, 2003). The present study indicates that a high proportion of demersal fishes such as *O. cuvieri, S. tumbil, S. kobiensis, Plicofollis dussumieri* and *S. jello* in Group A were separated from others. Group B has a relatively high proportion of *P. hamrur, E. diacanthus, A. atropos* and *U. sulphureus* whereas Group C was dominated by *S. elliptica, S. pharaonis, J. glaucus* and *E. chabaudi*. Group D has a higher proportion of *M. cordyla, C. talabonoides, Platycephalus indicus* and *A. monoceros* whereas Group E had a higher proportion of *Lagocephalus inermis, Sepiella. inermis, Odonus niger* and *Octopus membranaceus.*

The bycatch analysis revealed that the bycatch and the consequent discards are relatively lower in the mid-water trawl fisheries operated specifically for ribbonfishes as compared to what has been reported for shrimp and demersal fish trawlers in the NWCI region (Fennessy and Groeneveld, 1997; Bijukumar and Deepthi, 2009; Velip and Rivonker, 2015; Samanta *et al.,* 2018). However, the proportion of bycatch is higher here as compared to similar fisheries in other parts of the world such as the New Zealand jack mackerel fishery, Dutch pelagic freezer-trawl fishery and south African midwater trawl fishery for horse mackerel (Anderson, 2004; Hofstede and Dickey-Collas, 2006; Borges *et al.,* 2008; Reed *et al.,* 2017). Variations in bycatch species diversity and the catch rates in the fishery could be attributed to increased effort by midwater trawlers targeting ribbonfishes in the inshore areas (within 50 m depth) and the use of smaller cod end mesh size (<40 mm). Moreover, inshore areas serve as vital nursery grounds for numerous fish species, contributing significantly to their recruitment (Camp *et al.,* 2011; Sheaves *et al.,* 2014). Additionally, the clustering of fish populations and their seasonal movements play essential roles in facilitating feeding, reproduction and the avoidance of unfavorable environmental conditions (Northcote, 1978; Stobutzki *et al.,* 2001; Olsson *et al.,* 2006; Azeez *et al.,* 2023b). Hence, it is suggested that

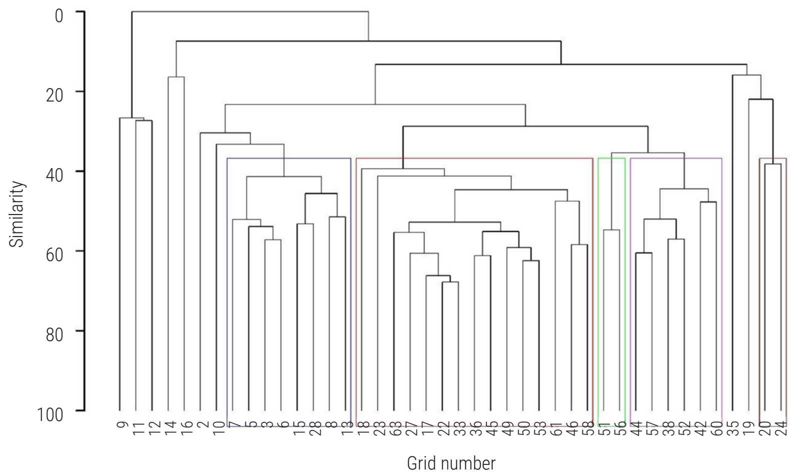

Fig. 8. Dendrogram showing the similarity in species composition of mid-water trawl bycatch among the grid blocks. Blue, red, green, purple and brown boxes were represented as A, B, C, D, and E groups respectively

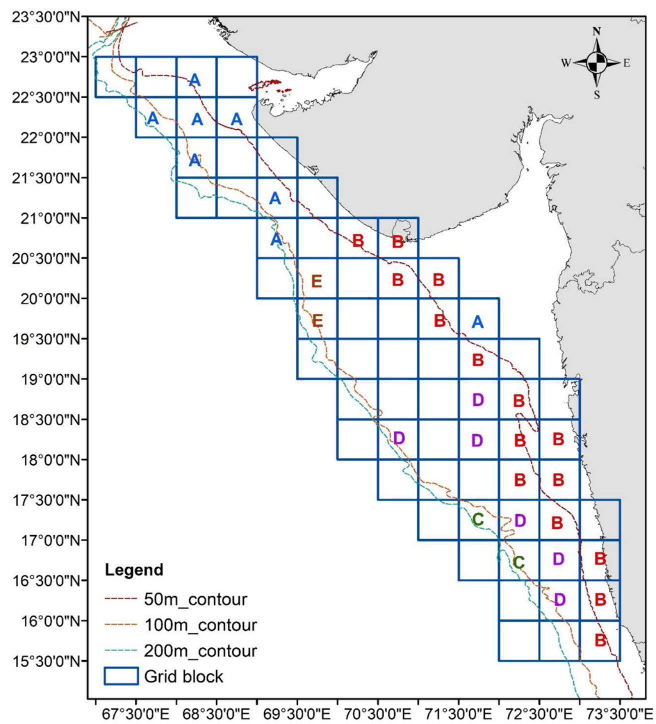

Fig. 9. Map of the North-West coast of India showing Groups A, B, C, D, and E identified by cluster analysis of the species composition in mid-water trawl bycatch

mid-water trawl fisheries targeting ribbonfish in NWCI use bycatch reduction devices in the gear and limit their operations beyond the 50 m depth zone to reduce the bycatch to a great extent. However, the quantum of catch reduction, the economic viability of the modified gear as well as area-based management for the mid-water trawl fishery targeting ribbonfish needs to be studied in detail. Continuous monitoring of the fishery with the participation of the fishermen would aid in the effective implementation of the regulations as well as help gain further insights into the spatial and temporal dynamics of the target and bycatch species.

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