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Research Article

Bycatch and discards in the shrimp trawl fishery off the Persian Gulf

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Abstract

The Persian Gulf waters, like other tropical regions, are rich in aquatic animal fauna and demersal trawling is one of the most common and practical methods to exploit aquatic resources. In the meantime, fishing vessels equipped with trawl nets can generate large amounts of bycatch and subsequent discards. This study aimed to identify fish species and estimate catch per unit area (CPUA) in the shrimp trawl bycatch off northwestern coasts of the Persian Gulf. The data were collected during trawl hauls for one year (September 2021– September 2022) between Delwar and Helle fishing grounds at three depth layers. The bycatch samples included 75 fish species with a total CPUA of 2392.4 kg/nm^2. The largest amount of the discarded bycatch (77.8%) belongs to teleost and cartilaginous fishes, of which gilded goatfish and Japanese threadfin bream accounted for the first and second places with a total CPUA of 433.9 kg/nm^2 and 202.8 kg/nm^2, respectively. The abundance of the identified bycatch varied at different water layers, and the highest bycatch rate was obtained in the depth water (21-30 m; 44.1%) and the lowest value was recorded in the shallow water (up to 10 m; 21.7%). Fifteen fish species had percentage of occurrence (100%) at all studied depths. According to the distribution map provided by ArcGIS software, the density of discards was increased by moving toward the western part of the Persian Gulf. The assessment of the bycatch composition of traditional shrimp trawler fisheries is not only practical to take preventive actions regarding the marine ecosystem balance but also the results can be used as an ecological model to evaluate the risk of the trawlers in the study area.

Keywords: Bycatch, CPUA, Discards, Trawl, Arc IS, Fish species

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Introduction

Several aquatic animals are being discarded worldwide by commercial fishing efforts, which are responsible to generate 9.1 million tonns of discard annually or nearly 11% of the global catch (Gilman *et al.,* 2020). Bycatch includes the aquatic animals that are caught along with the target species and it is divided into commercial and non-commercial organisms. The identified reasons for discarding aquatic animals by fishermen can be related to poisonous and inedible organisms, unacceptable small size and lack of consumer preference to eat, unavailable storage space in the vessels, high physical damages during the fishing operations due to their small sizes, no available industries to process and package, and catching illegal aquatic animals in the fishing grounds (Thomas *et al.,* 2017; Ramkumar *et al.*, 2019). Discards are one of the main concerns of marine biologists in the fishing industry and there are several solutions proposed and tested to reduce the bycatch and consequently discards in the fishing gears that are prone to huge bycatch rates (Catchpole *et al.,* 2005; Pandey *et al.*, 2020). This concern is exacerbated when fishing operates in tropical and subtropical areas that have a high diversity of potential aquatics to be discarded (Bellido *et al.,* 2011). In this regard, demersal or bottom trawling has a high rate of discarding with more than half of the total estimated discards in the world and tropical shrimp trawl fisheries contributed to produce the highest discard rate (Roda *et al.*, 2019; Mendo *et al.*, 2022).

Fisheries exploitation of fish and shellfish in the Persian Gulf has its roots in ancient times due to the remarkable diversity of aquatic animals in this tropical region (Valinasab *et al.,* 2006a). Although the amounts of bycatch produced in various fishing methods depend on the fishing gears, demersal or bottom trawl generates substantial amounts of bycatch, meanwhile, some of them have commercial importance and some others maybe have a less or non-economic value that makes them huge discards (Fonseca *et al*., 2005). The shrimp trawl net is one of the common fishing gears in the Persian Gulf, which is used during the shrimp fishing seasons (Valinassab *et al.,* 2006a). However, shrimp trawlers are responsible to have at least 74% bycatch of the total catch in tropical areas (Velip and Rivonker, 2015). Overfishing of non-target species or discards can negatively affect the wildlife ecological balance in the marine ecosystem and finally leads to a decrease in fishing efforts and threatens coastal economies and food security (Gislason, 2003; Gupta *et al.,* 2019; Ramkumar *et al.,* 2019; Carvalho *et al.,* 2020). Therefore, it is necessary to continuously monitor the aquatic discards by collecting biological and fishing data as well as recognizing the composition of shrimp trawling.

Up to now, several studies have been conducted to estimate the bycatch rate and composition of the Persian Gulf in different fishing grounds (Valinassab *et al.,* 2006a,b; Hosseini *et al.,* 2012;

Eighani and Paighambari, 2013; Farrokhi *et al.*, 2015; Ghotbeddin *et al.*, 2015; Sabet *et al.*, 2018; Tajzadehnamin *et al.*, 2020). In this context, the significant values of the bycatch portion (more than 65%; Valinassab *et al.*, 2006b) and rate of discards in the total catch (Eskandari *et al.*, 2016) are estimated in the Persian Gulf waters by traditional shrimp fishing vessels. For instance, 76.33% of the total shrimp trawl catch was discarded in Hormuzgan province, Persian Gulf (Farrokhi *et al.*, 2014). In another similar study in the region, 13.7% of the total catch was related to the targeted species (shrimp) and 71.51% of the total bycatch was discarded in Hormuzgan province by shrimp trawling vessels (Paighambari *et al.*, 2017). These findings raise many concerns about the adverse effects of shrimp trawl nets on the non-target species that are discarded in the Persian Gulf and elucidate the necessity for conducting more research regarding the discards generated by fishing vessels in the region.

There is little information to focus on the assessment of shrimp trawl discards in the Persian Gulf. Hence, this research was performed to provide an assessment of the discard composition from shrimp trawls at different depths and areas in Bushehr province (Delwar to Helle fishing grounds), northwest of the Persian Gulf.

Material and methods

Study area and sampling

The study area is located on the northwest part of the Persian Gulf (Iranian waters) and it included the Iranian coasts from Delwar in the southern part to Helle shores in the north. Accordingly, each area was divided into 3 sub-areas, which were classified into coastal (up to 10 m), medium depth waters (11-20 m), and deeper waters (21-30 m) water layers. The area of each sub-region includes a percentage of the total area of the study area at different depths and the number of stations considered in each sub-region was directly proportional to the share of the area of that sub-region in the total study area (Fig. 1).

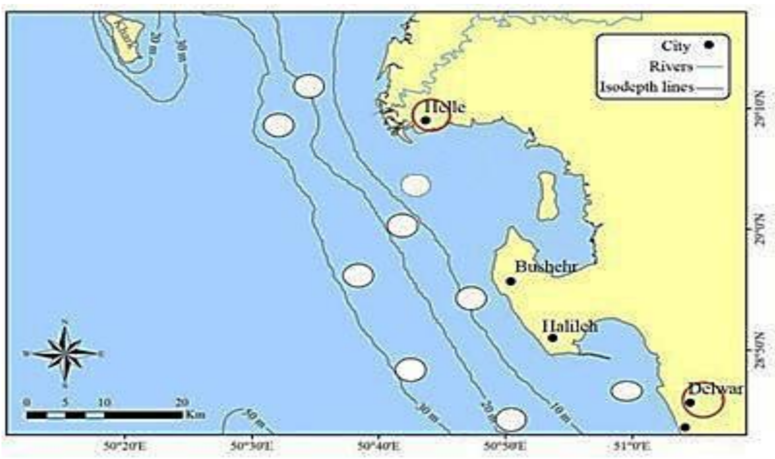

Figure 1: Map of study area in the northwest part of the Persian Gulf (white dots: sampling areas).

The location of the stations was recorded using GPS systems. To collect the samples, the stations are divided into north, center, and southern regions. The geographic locations of the fishing grounds are summarized in Table 1.

Table 1: Geographical location of sampling stations in the present study.

Region	Station	Longitude(E)	Latitude(N)
Delwar (28º56'N, 50º34'E)	1	50.8932	28.6352
	2	50.7099	28.5834
	3	50.5865	28.6250
Bushehr (28º33'N, 50º42'E)	1	50.7080	28.8526
	2	50.4756	28.8434
	3	50.5907	28.9510
Helleh (28º45'N, 51º05'E)	1	50.7185	29.0527
	2	50.5124	29.0971
	3	50.5030	29.1570

This research was carried out for one year (September 2021 to September 2022) in the northern Persian Gulf and Sampling was conducted in the waters of the three regions and up to the territorial waters (up to 12 nautical miles after the starting line) and with two repetitions using the traditional shrimp trawl fishing method.

In this study, three traditional shrimp trawlers were used and each one was equipped with polyamide bottom trawl nets and 31 m headrope. The stretched mesh sizes in the panel and codend were 40 and 24 mm, respectively. Sampling operations were carried out during 36 cruises and the average hauling duration was 120 min. The speed of the cruises was 2.5–3.0 knot. The fishing efforts were performed almost in calm and sunny weather conditions. A GPS Plotter Fish-Finder (OVA T80F, Jiangsu, China) was also used during the trawling survey.

Bycatch composition

After each hauling, the codend was unloaded on the deck and the total weight of the catch was recorded prior to the fish sorting. Then target (shrimps) and commercial aquatic species were first separated from the total catch and then, large and venomous aquatic animals such as sharks and rays, were separated, counted, and weighed from the bycatch and returned to the sea. The rest of the discards were completely mixed and one-fifth of the fish species was randomly sampled based on the volume and size of the organisms to ensure an uncertainty level of 5% (Herrmann *et al.,* 2016).

Finally, the sampled fish species were identified using valid identification keys (*i.e.* Smith and Heemstra, 1986; Nelson *et al.,* 2016), weighed, and recorded in special sheets for each station and depth. Plastic baskets (total capacity=5 kg) were used for sampling, separating, and weighting the catch.

Catch Per Unit Area (CPUA)

The following formulas and methods were used to compute the CPUA for the discards (Sparre and Venema, 1998):

$$D = V \times t$$

Where, D: the distance traveled during net hauling, V: the average speed of the vessel at the time of net hauling, t: duration of net hauling (h).

$$a = d \times h \times x_2$$

Where, a is the swept area (nm^2), d is the distance traveled net hauling (nmi), h is the length of the upper rope (nmi), and x_2 is the expansion coefficient (0.65).

$$CPUA = \frac{Cw}{a}$$

Where, CPUA is the catch per unit area (kg/nm^2), *Cw* is the total weight of all species at the station (kg), and a is the swept area at the station (nm^2).

Species occurrence index

The percentage occurrence for each species was calculated from the following formula (Dos Santos *et al.*, 2002):

$$\text{Species occurrence (\%)} = \frac{\rho i}{P} \times 100$$

Where, ρ: the number of fishing efforts that the species *i* was collected, and P: total number of fishing efforts.

Software and data analysis

All the data were entered in the Excel (v. 2013) software and the graphs were plotted by this software. The distance traveled at each station was calculated and recorded by a plotter device. Also, ArcGIS version 9 was used to draw the distribution maps for the dominant discards.

Results

Bycatch composition

As Table 2 shown, 75 fish species were identified in different stations and depths. The highest abundance of fish species in the total bycatch was observed for gilded goatfish (18.1%), and the second and third places belonged to Japanese threadfin bream (8.4%) and rays (6.3%). The highest and lowest abundance of fish species in the total bycatch was recorded at deep and shallow water depths, respectively. Meanwhile, at the mid depth, the highest abundance was related to rays. By increasing the depth layers, the maximum abundance was recorded for gilded goatfish followed by Japanese threadfin bream.

Table 2: Abundance (%) of the bycatch from the traditional shrimp trawlers in Bushehr offshores (Delwar to Helle; Persian Gulf, Iran) at different depth layers (m) from September 2021 to September 2022.

Scientific name	Common name	Different water depths			
		Shallow depth	Medium depth	High depth	Whole area
Pseudorhombus elevatus	Deep flounder	0.3	0.6	0.5	1.3
Psettodes erumei	Indian halibut	0.0	0.0	0.0	0.1
Euryglossa orientalis	Orienttal sole	0.2	0.5	0.5	1.2

Table 2 continued:

Scientific name	Common name	Different water depths			
		Shallow depth	Medium depth	High depth	Whole area
Cynoglossus arel	Fourlined tonguesole	0.4	0.4	0.1	1.0
Chirocentrus nudus	Whitefin wolf-herring	0.0	0.1	0.3	0.4
Anodontostoma chacunda	Chacunda gizzard shad	1.2	1.9	0.4	3.5
Nematolosa nasus	Gizzard's shad	0.4	0.9	0.3	1.6
Dussumieria acuta	Slender rainbow sardine	0.0	0.1	0.0	0.1
Tenualosa ilisha	Hilsha shad	0.0	0.0	0.0	0.1
Ilisha megaloptera	Bigeye ilisha	1.1	0.6	0.5	2.1
Ilisha melastoma	Indian ilisha	0.8	0.4	0.4	1.5
Stolephorus indicus	Indian anchovy	0.1	0.3	0.0	0.4
Chelonodon patoca	Milk spotted puffer	0.6	0.6	0.6	1.8
Triacanthus biaculeatus	Shortnose tripondfish	0.1	0.1	0.1	0.3
Cyclichthys orbicularis	Orbicular burfish	0.0	0.0	0.0	0.1
Muraenenesox cinereus	Daggertooth pike conger	0.1	0.3	0.8	1.1
Tylosurus crocodilus	Hound needlefish	0.3	0.1	0.1	0.4
Seriolina nigrofaciata	Blackbanded trevally	0.0	0.0	0.0	0.1
Caranx sem	Blacktip trevally	0.0	0.0	0.0	0.1
Caranx sexfaciatus	Bigeye trevally	0.0	0.0	0.0	0.1
Alectis indicus	Indian threadfish	0.0	0.0	0.0	0.1
Scomberoides commersonnianus	Talang queenfish	0.2	0.4	0.2	0.8
Parastromateus niger	Black pomfret	0.1	0.6	0.6	1.4

Table 2 continued:

Scientific name	Common name	Different water depths			
		Shallow depth	Medium depth	High depth	Whole area
Acanthopagrus latus	Yellowfin seabream	0.3	0.3	0.3	0.8
Argyrops spinifer	King soldier bream	0.2	1.1	0.9	2.2
Acanthopagrus cuvieri	Silver seabream	0.0	0.1	0.0	0.2
Diplodus sargus kotschyi	Onespot seabream	0.4	0.5	0.4	1.3
Gerres poieti	Strongstripe silver-biddy	0.3	0.2	0.8	1.3
Lutjanus malabaricus	Malabar blood snapper	0.0	0.1	0.1	0.2
Lutjanus Johni	John’s snapper	0.1	0.2	0.1	0.4
Siganus sutor	Shoemaker	0.0	0.0	0.0	0.0
Sphyraena jello	Pickhandle barracuda	0.1	0.4	0.2	0.7
Sphyraena obtusata	Obtuse barracuda	0.1	0.2	0.1	0.3
Pomadasys kaakan	Javelin grunter	0.1	0.3	0.3	0.6
Diagramma pictum	Painted sweetlips	0.1	0.1	0.0	0.2
Plectorhinchus pictus	Trout sweetlips	0.0	0.0	0.0	0.1
Scarus ghobban	Yellowscale parrotfish	0.0	0.0	0.0	0.0
Heniochus acuminatus	Longfin bannerfish	0.0	0.0	0.0	0.0
Lethrinus nebulosus	Spangled emperor	0.2	0.4	0.5	1.1
Epinephelus chlorostigma	Brownspotted grouper	0.0	0.0	0.0	0.1
Epinephelus coioides	Orangespotted grouper	0.3	0.6	0.2	1.1
Epinephelus latifasciatus	Striped grouper	0.0	0.1	0.1	0.2
Liza abu	Abu mullet	0.4	0.5	0.3	1.3
Mugil cephalus	Flathead mullet	0.3	0.2	0.1	0.6
Pampus argenteus	Silver pomfret	0.2	0.3	0.4	0.9
Eleutheronema tetradactylum	Fourfinger threadfin	0.0	0.0	0.1	0.1
Otolithes ruber	Tigertooth croaker	0.4	1.7	0.3	2.4
Pennahia macrophthalmus	Bigeye croaker	0.2	0.7	0.5	1.4
Argyrosomus hololepidotus	Southern meagre	0.6	0.8	0.7	2.1
Sillago sihama	Silver sillago	1.4	0.5	0.3	2.1
Pomacanthus maculosus	Yellowbar angelfish	0.0	0.0	0.0	0.0
Scomberomorus commerson	Narrowbarred Spanish mackerel	0.4	1.3	0.9	2.7
Scomberomorus guttatus	Indo-Pacific king mackerel	0.3	0.9	0.3	1.5
Euthynus affinis	Kawakawa	0.1	0.2	0.2	0.4
Upeneus sulphureus	Gilded goatfish	3.2	4.0	11.1	18.3
Mene maculata	Moonfish	0.0	0.0	0.2	0.2

Table 2 continued:

Scientific name	Common name	Different water depths			
		Shallow depth	Medium depth	High depth	Whole area
Platax orbicularis	*Orbicularis batfish*	0.0	0.0	0.0	0.0
Thrichiurus lepturus	Largehead hairtail	0.5	1.5	2.8	4.8
Leiognathus bindus	Orangefin ponyfish	0.2	0.3	0.4	0.9
Leiognathus lineolatus	Oblong ponyfish	0.2	0.3	0.2	0.7
Rachycentron canadum	Cobia	0.0	0.0	0.0	0.0
Pelates quadrilineatus	Fourlined terapon	0.5	0.3	0.2	1.1
Nemipterus japonicus	Japanese threadfin bream	0.8	1.9	5.7	8.5
Drepane punctata	Spotted sicklefish	0.0	0.0	0.0	0.0
Pseudosynanceia melanostigma	Blackfin stonefish	0.1	0.0	0.1	0.2
Pterois russellii	Plaintail turkeyfish	0.0	0.0	0.0	0.1
Platycephalus indicus	Bartail flathead	0.6	1.1	4.0	5.7
Arius dussumieri	Blacktip sea catfish	0.2	0.7	1.8	2.7
Saurida tumbil	Greater lizardfish	0.1	0.3	1.4	1.8
Carcharhinus dussumieri	Whitecheek shark	0.1	0.3	0.4	0.8
Rhinobatus annandalei	Guitarfish	0.0	0.0	0.0	0.1
Chiloscyllium punctatum	Brownbanded bambooshark	0.1	0.2	0.8	1.0
Himantura walga	Scaly stingray (ray)	2.4	2.7	0.9	5.9
Dasyatis bennetti	Bennett's stingray (ray)	0.1	0.1	0.1	0.4
Torpedo sinuspersici	Marbled electric ray	0.0	0.3	0.4	0.7
Total (%)		21.6	34.1	44.2	100

Notes. 0.0: the frequency value was less than 0.1%. –: the frequency value was zero. Shallow depth: coastal waters (up to 10m), medium depth: 11-20 m, and high: 21-30 m.

The results of this study showed that 78 % of the total fish species bycatch was discards. Also, 22% of the total bycatch was recognized as commercial fishes (including flounders, sea breams, snappers, and groupers) and, Flathead which was more abundant in deep water layers (Fig. 2).

The species frequency of the bycatch at different depth layers based on the different fish species is illustrated in Figure 3.

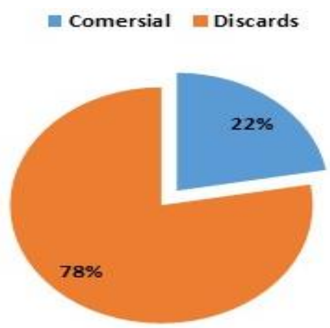

Figure 2: The frequency (%) of discards and commercial fish species at different water layers from Bushehr offshores (NW; Persian Gulf, Iran) on September 2021 to September 2022. Shallow, medium, and high depth layers were related to the coastal waters (up to 10 m), 11-20 m, and 21-30 m, respectively.

The gilded goatfish and Japanese threadfin bream were scattered at different depth layers, while, silver sillago, ilishas, and hound needlefish were more abundant in the coastal waters. Deep flounder, bigeye croaker, and narrowbarred Spanish mackerel were abundant at the medium depths. However, largehead hairtail, and strongstrips silver-biddy were abundant in deep water layers (21-30 m depth), (Fig. 3).

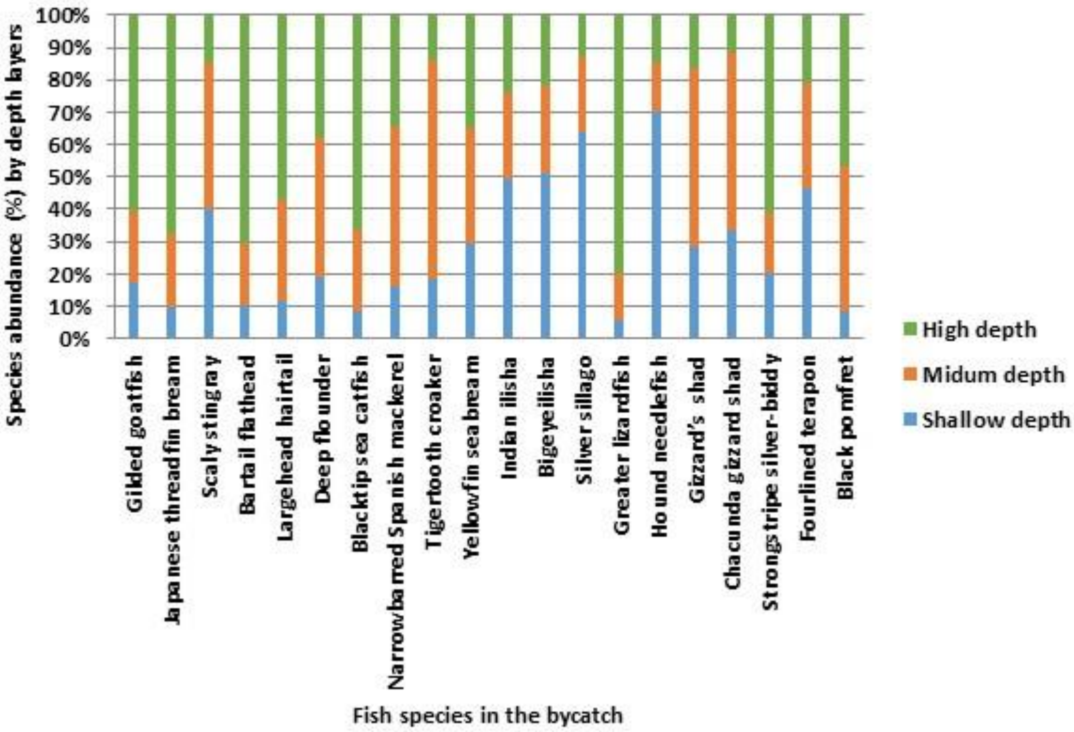

Figure 3: Fish species abundance of the bycatch at different depth layers by the shrimp trawlers in Bushehr offshores (Delwar to Helle; Persian Gulf, Iran) on September 2021 to September 2022. Shallow depth: coastal waters (up to 10 m), medium depth: 11-20m, and high depth: 21-30 m.

The total abundance fish species of the bycatch in terms of number and weight is shown for three studied areas in Bushehr province (Helle, Bushehr, and Delwar regions) in Figure 4. The total number of fish species of the bycatch in Delwar region was higher than in Helle and Bushehr regions. In addition, the weight abundance of the bycatch in Helle region was lower than other two regions.

CPUA value of discards

The total CPUA value in the study area was 2392.4 kg/nm^2, and the highest and lowest values were obtained at the deep (1056.2 kg/nm^2) and low (520.4 kg/nm^2) water strata, respectively. The highest CPUA value of the total bycatch was measured for gilded goatfish (436.9 kg/ nm^2) followed by Japanese threadfin bream (202.8 kg/nm^2). The lowest value of CPUA was measured for longfin bannerfish (0.1 kg/nm^2) and yellowbar angelfish (0.8 kg/nm^2).

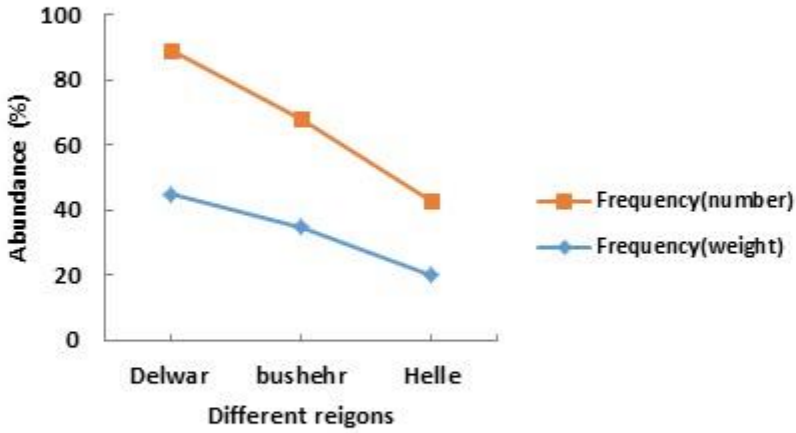

Figure 4: Changes in the species abundance (%) of bycatch from the shrimp trawlers at different regions in Bushehr province, Persian Gulf, Iran.

At shallow depths, the highest value of CPUA was recorded for ilishas, followed by silver sillago and hound needlefish. The shads and tigertooth croaker had the highest amount of CPUA at medium depths. However, the highest CPUA value was for gilded goatfish and Japanese threadfin bream at high depths. Finally, the gilded goatfish, Japanese threadfin bream and rays had the highest CPUA values in the whole area in the first to third places, respectively (Table 3).

Table 3: CPUA value (kg/nm^2) of the bycatch from the traditional shrimp trawlers in Bushehr offshore (Delwar to Helle; Persian Gulf, Iran) at different depth layers (m) on September 2021 to September 2022.

Scientific name	Common name	Different depth layers (kg/nm^2)			
		Shallow depth	Medium depth	High dept h	Whole area
Pseudorhombus elevatus	Deep flounder	5.97	13.67	12.06	31.7
Psettodes erumei	Indian halibut	0.66	1.15	0.69	2.5
Euryglossa orientalis	Orienttal sole	4.63	11.68	12.70	29.01
Cynoglossus arel	Fourlined tonguesole	9.07	10.67	3.37	23.1
Chirocentrus nudus	Whitefin wolf-herring	0.75	2.44	6.23	9.41
Anodontostoma chacunda	Chacunda gizzard shad	28.04	45.57	9.65	83.26
Nematolosa nasus	Gizzard's shad	10.68	20.88	6.20	37.76
Dussumieria acuta	Slender rainbow sardine	1.04	1.33	0.67	3.04
Tenualosa ilisha	Hilsha shad	0.88	0.75	0.52	2.15
Ilisha megaloptera	Bigeye ilisha	25.70	13.72	11.05	50.47
Ilisha melastoma	Indian ilisha	17.96	9.63	8.75	36.33
Stolephorus indicus	Indian anchovy	1.87	6.27	0.67	8.8
Chelonodon patoca	Milkspotted puffer	14.23	15.35	13.33	42.91
Triacanthus biaculeatus	Shortnose tripondfish	3.23	3.37	1.23	7.83
Cyclichthys orbicularis	Orbicular burfish	0.88	0.98	0.35	2.21

Table 3 continued:

Scientific name	Common name	Different depth layers (kg/nm^2)			
		Shallow depth	Medium depth	High depth	Whole area
Muraenenesox cinereus	Daggertooth pike conger	1.98	6.21	18.00	26.19
Tylosurus crocodilus	Hound needlefish	7.13	1.52	1.47	10.11
Seriolina nigrofaciata	Blackbanded trevally	0.23	0.77	1.20	2.21
Caranx sem	Blacktip trevally	0.69	0.87	0.51	2.07
Caranx sexfaciatus	Bigeye trevally	0.41	0.35	1.04	1.8
Alectis indicus	Indian threadfish	0.69	1.16	0.60	2.45
Scomberoides commersonnianus	Talang queenfish	3.64	10.65	3.66	17.95
Parastromateus niger	Black pomfret	2.80	14.70	15.33	32.83
Acanthopagrus latus	Yellowfin seabream	6.00	7.34	7.10	20.44
Argyrops spinifer	King soldier bream	4.42	26.55	21.67	52.63
Acanthopagrus cuvieri	Silver seabream	0.67	1.93	0.90	3.5
Diplodus sargus kotschyi	Onespot seabream	10.73	12.27	9.00	32
Gerres poieti	Strongstripe silver-biddy	6.18	5.67	18.49	30.34
Lutjanus malabaricus	Malabar blood snapper	1.04	1.85	2.32	5.21
Lutjanus Johni	John’s snapper	1.27	5.00	3.23	9.5
Siganus sutor	Shoemaker	0.46	0.70	0.00	1.16
Sphyraena jello	Pickhandle barracuda	1.80	8.93	5.21	15.94
Sphyraena obtusata	Obtuse barracuda	1.45	4.06	1.75	7.26
Pomadasys kaakan	Javelin grunter	2.04	6.23	6.53	14.81
Diagramma pictum	Painted sweetlips	1.64	3.01	0.80	5.45
Plectorhinchus pictus	Trout sweetlips	0.99	0.87	0.73	2.59
Scarus ghobban	Yellowscale parrotfish	0.00	1.15	0.00	1.15
Heniochus acuminatus	Longfin bannerfish	0.15	0.00	0.00	0.15
Lethrinus nebulosus	Spangled emperor	4.10	10.67	12.35	27.12
Epinephelus chlorostigma	Brownspotted grouper	0.46	0.65	0.11	1.22
Epinephelus coioides	Orangespotted grouper	7.41	14.29	4.72	26.42
Epinephelus latifasciatus	Striped grouper	1.04	1.45	1.71	4.21
Liza abu	Abu mullet	10.21	12.33	8.00	30.54
Mugil cephalus	Flathead mullet	7.27	5.00	2.03	14.3
Pampus argenteus	Silver pomfret	5.67	6.09	9.54	21.3

Table 3 continued:

Scientific name	Common name	Different depth layers (kg/nm²)			
		Shallow depth	**Medium depth**	**High depth**	**Whole area**
Eleutheronema tetradactylum	Fourfinger threadfin	0.65	0.80	1.46	2.91
Otolithes ruber	Tigertooth croaker	10.67	39.83	8.08	58.58
Pennahia macrophthalmus	Bigeye croaker	4.62	17.67	11.67	33.95
Argyrosomus hololepidotus	Southern meagre	14.85	19.67	16.74	51.26
Sillago sihama	Silver sillago	32.20	11.50	6.56	50.26
Pomacanthus maculosus	Yellowbar angelfish	0.00	0.83	0.00	0.83
Scomberomorus commerson	Narrowbarred Spanish mackerel	10.17	31.57	22.17	63.9
Scomberomorus guttatus	Indo-Pacific king mackerel	6.09	22.33	6.80	35.22
Euthynus affinis	Kawakawa	1.45	3.89	4.34	9.68
Upeneus sulphureus	Gilded goatfish	76.59	94.99	265.32	436.9
Mene maculata	Moonfish	0.00	0.00	5.43	5.43
Platax orbicularis	*Orbicularis batfish*	0.26	0.78	0.00	1.04
Thrichiurus lepturus	Largehead hairtail	13.33	36.00	66.18	115.52
Leiognathus bindus	Orangefin ponyfish	5.65	6.07	10.09	21.81
Leiognathus lineolatus	Oblong ponyfish	3.93	8.18	4.30	16.41
Rachycentron canadum	Cobia	0.00	0.00	0.92	0.92
Pelates quadrilineatus	Fourlined terapon	12.00	8.31	5.50	25.81
Nemipterus japonicus	Japanese threadfin bream	19.97	46.00	136.92	202.89
Drepane punctata	Spotted sicklefish	0.00	0.00	1.11	1.11

Table 3 continued:

Scientific name	Common name	Different depth layers (kg/nm^2)			
		Shallow depth	**Medium depth**	**High depth**	**Whole area**
Pseudosynanceia melanostigma	Blackfin stonefish	1.40	0.87	1.42	3.69
Pterois russellii	Plaintail turkeyfish	0.40	1.04	0.53	1.97
Platycephalus indicus	Bartail flathead	14.12	26.65	96.00	136.77
Arius dussumieri	Blacktip sea catfish	5.37	16.33	42.82	64.52
Saurida tumbil	Greater lizardfish	2.53	6.10	34.53	43.16
Carcharhinus dussumieri	Whitecheek shark	3.24	6.33	10.34	19.91
Rhinobatus annandalei	Guitarfish	0.00	0.72	1.16	1.88
Chiloscyllium punctatum	Brownbanded bambooshark	1.33	4.60	18.08	24.01
Himantura walga	Scaly stingray (ray)	57.27	64.27	20.65	142.18
Dasyatis bennetti	Bennett's stingray (ray)	3.24	3.37	2.52	9.12
Torpedo sinuspersici	Marbled electric ray	0.96	7.34	9.17	17.47
		520.41	815.78	1056.25	2392.44

Notes. Shallow depth: coastal waters (up to 10 m), medium depth: 11-20 m, and high depth: 21-30 m.

As Figure 5 illustrated, CPUA value of the fish species bycatch showed an increasing trend by increasing depth and the highest value was observed at deep layers (1056.2 kg/nm^2)

According to Figure 6, the distribution of the fish species bycatch off Bushehr waters showed a higher and according to the distribution map, Delwar region had more bycatch compared to other regions. Also, the distribution map indicated the horizontal distribution of the fish species in the bycatch from the west direction of Bushehr waters. The total bycatch volume was decreased in the northwest of Bushehr offshores with increasing depths, however, fish species of the bycatch were increased by moving to the south and west with increasing depths.

Species occurrence index

The results of the fish species occurrence index are shown in Table 4. Fifteen fish species were bycatch at the highest probability (100%) in the whole region at different depths. Rays were also had the highest possibility to catch among the bycatch of cartilaginous fish in the regions. At shallow depths, there was a 100% occurrence of silver sillago and shads in the bycatch. At the medium depths, the species occurrence was maximum (100%) for tigertooth croaker and narrowbarred Spanish mackerel in the bycatch. At deep water, largehead hairtail, and orangespotted grouper had 100% occurrence in the bycatch. The species occurrence index was below 10% for the bycatch longfin bannerfish, Indian halibut and moonfish in the whole region at different depths.

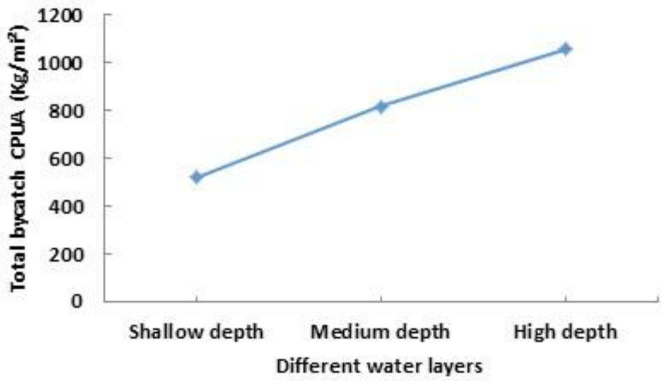

Figure 5: Changes in the CPUA mean value (kg/nm^2) of the bycatch from the traditional shrimp trawlers at different water layers in Bushehr province, Persian Gulf, Iran. Shallow depth: coastal waters (up to 10 m), medium depth: 11-20 m, and high depth: 21-30 m.

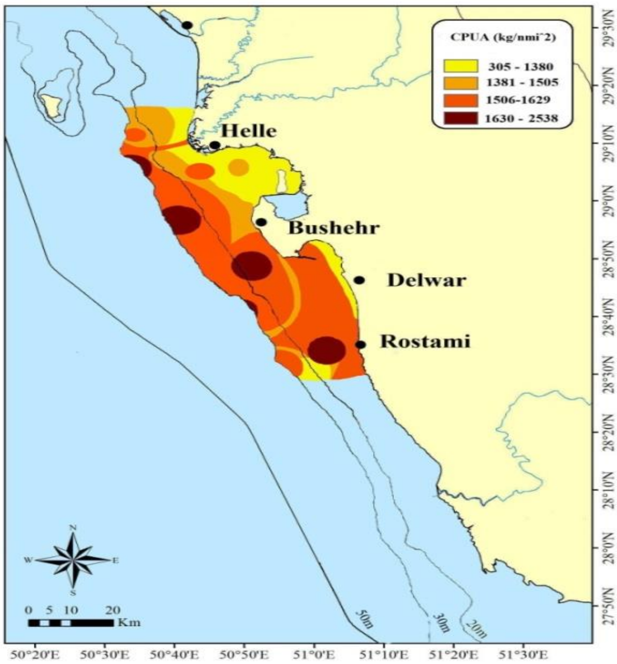

Figure 6: Dispersion map of the bycatch by ArcGIS software based on the CPUA data in Bushehr offshores, Persian Gulf, Iran.

Table 4: Species occurrence index (%) of the bycatch from the traditional shrimp trawlers in Bushehr offshores (Delwar to Helle; Persian Gulf, Iran) at different depth layers (m) on September 2021 to September 2022.

Scientific name	Common name	Different depth layers			
		Shallow depth	Medium depth	High depth	Whole area
Pseudorhombus elevatus	Deep flounder	11.1	44.4	33.3	29.6
Psettodes erumei	Indian halibut	2.7	2.7	2.7	2.7
Euryglossa orientalis	Orienttal sole	33.3	88.8	88.8	70.3
Cynoglossus arel	Fourlined tonguesole	100	100	100	100
Chirocentrus nudus	Whitefin wolf-herring	11.1	44.4	88.8	48.1
Anodontostoma chacunda	Chacunda gizzard shad	100	100	66.6	88.8
Nematolosa nasus	Gizzard's shad	100	100	66.6	88.8
Dussumieria acuta	Slender rainbow sardine	11.1	11.1	11.1	11.1
Tenualosa ilisha	Hilsha shad	11.1	11.1	11.1	11.1
Ilisha melastoma	Bigeye ilisha	100	88.8	66.6	85.1
Ilisha megaloptera	Indian ilisha	100	88.8	55.5	81.4
Stolephorus indicus	Indian anchovy	88.8	88.8	33.3	70.3
Chelonodon patoca	Milkspotted puffer	66.6	66.6	55.5	62.9
Triacanthus biaculeatus	Shortnose tripondfish	33.3	33.3	11.1	25.9
Cyclichthys orbicularis	Orbicular burfish	33.3	66.6	66.6	55.5
Muraenenesox cinereus	Daggertooth pike conger	11.1	44.4	66.6	40.7
Tylosurus crocodilus crocodilus	Hound needlefish	100	22.2	22.2	48.1
Seriolina nigrofaciata	Blackbanded trevally	11.1	22.2	22.2	18.5
Caranx sem	Blacktip trevally	22.2	33.3	11.1	22.2
Caranx sexfaciatus	Bigeye trevally	22.2	22.2	44.4	29.6

Table 4 continued:

Scientific name	Common name	Different depth layers			
		Shallow depth	Medium depth	High depth	Whole area
Alectis indicus	Indian threadfish	22.2	33.3	11.1	22.2
Scomberoides commersonnianus	Talang queenfish	11.1	33.3	11.1	18.5
Parastromateus niger	Black pomfret	22.2	66.6	100	62.9
Acanthopagrus latus	Yellowfin seabream	66.6	100	66.6	77.7
Argyrops spinifer	King soldier bream	66.6	100	100	88.8
Acanthopagrus cuvieri	Silver seabream	11.1	33.3	11.1	18.5
Diplodus sargus kotschyi	Onespot seabream	100	100	100	100
Gerres poieti	Strongstripe silver-biddy	100	100	100	100
Lutjanus malabaricus	Malabar blood snapper	11.1	33.3	22.2	22.2
Lutjanus Johni	John's snapper	11.1	33.3	66.6	37
Siganus sutor	Shoemaker	11.1	22.2	0	11.1
Sphyraena jello	Pickhandle barracuda	11.1	44.4	66.6	40.7
Sphyraena obtusata	Obtuse barracuda	11.1	33.3	33.3	25.9
Pomadasys kaakan	Javelin grunter	11.1	33.3	44.4	29.6
Diagramma pictum	Painted sweetlips	22.2	66.6	33.3	40.7
Plectorhinchus pictus	Trout sweetlips	22.2	22.2	22.2	22.2
Scarus ghobban	Yellowscale parrotfish	0	33.3	0	11.1
Heniochus acuminatus	Longfin bannerfish	5.5	0	0	1.8
Lethrinus nebulosus	Spangled emperor	44.4	66.6	77.7	62.9

Table 4 continued:

Scientific name	Common name	Different depth layers			
		Shallow depth	**Medium depth**	**High depth**	**Whole area**
Epinephelus chlorostigma	Brownspotted grouper	11.1	22.2	11.1	14.8
Epinephelus coioides	Orangespotted grouper	66.6	88.8	100	88.8
Epinephelus latifasciatus	Striped grouper	22.2	33.3	44.4	33.3
Liza abu	Abu mullet	100	100	100	100
Mugil cephalus	Flathead mullet	100	100	100	100
Pampus argenteus	Silver pomfret	44.4	55.5	66.6	55.5
Eleutheronema tetradactylum	Fourfinger threadfin	11.1	11.1	33.3	18.5
Otolithes ruber	Tigertooth croaker	77.7	100	88.8	88.8
Pennahia macrophthalmus	Bigeye croaker	33.3	88.8	88.8	70.3
Argyrosomus hololepidotus	Southern meagre	88.8	88.8	88.8	88.8
Sillago sihama	Silver sillago	100	88.8	66.6	85.1
Pomacanthus maculosus	Yellowbar angelfish	0	22.2	0	7.4
Scomberomorus commerson	Narrowbarred Spanish mackerel	66.6	100	88.8	85.1
Scomberomorus guttatus	Indo-Pacific king mackerel	22.2	88.8	88.8	66.6
Euthynus affinis	Kawakawa	11.1	22.2	33.3	22.2
Upeneus sulphureus	Gilded goatfish	100	100	100	100
Mene maculata	Moonfish	0	0	11.1	3.7
Platax orbicularis	*Orbicularis batfish*	11.1	22.2	0	11.1
Thrichiurus lepturus	Largehead hairtail	77.7	100	100	92.5

Table 4 continued:

Scientific name	Common name	Different depth layers			
		Shallow depth	**Medium depth**	**High depth**	**Whole area**
Leiognathus bindus	Orangefin ponyfish	100	100	100	100
Leiognathus lineolatus	Oblong ponyfish	100	100	100	100
Rachycentron canadum	Cobia	0	0	22.2	7.4
Pelates quadrilineatus	Fourlined terapon	100	100	100	100
Nemipterus japonicus	Japanese threadfin bream	100	100	100	100
Drepane punctata	Spotted sicklefish	0	0	22.2	7.4
Pseudosynanceia melanostigma	Blackfin stonefish	11.1	11.1	11.1	11.1
Pterois russellii	Plaintail turkeyfish	11.1	11.1	11.1	11.1
Platycephalus indicus	Bartail flathead	100	100	100	100
Arius dussumieri	Blacktip sea catfish	100	100	100	100
Saurida tumbil	Greater lizardfish	100	100	100	100
Carcharhinus dussumieri	Whitecheek shark	33.3	44.4	55.5	44.4
Rhinobatus annandalei	Guitarfish	0	22.2	22.2	14.8
Chiloscyllium punctatum	Brownbanded bambooshark	11.1	44.4	77.7	44.4
Himantura walga	Scaly stingray (ray)	100	100	100	100
Dasyatis bennetti	Bennett's stingray (ray)	100	100	100	100
Torpedo sinuspersici	Marbled electric ray	11.1	44.4	66.6	40.7

Notes. Shallow depth: coastal waters (up to 10 m), medium depth: 11-20 m, and high depth: 21-30 m.

Discussion

In recent years, there have been clear signs of overfishing and irrational exploitations in the Persian Gulf, which can cause serious problems for the wild stocks of aquatic animals, especially the benthic fauna, and significant economic losses to the fishing industry, especially for the coastal communities (Mirzaei *et al.,* 2015; Niamaimandi *et al.,* 2018). One of the available solutions to reduce discards from different fishing efforts is to conduct regular surveys to understand any possible changes in the natural aquatic populations to finally apply management measures to protect the stocks (Bellido *et al.*, 2011). This study estimated the composition and proportion of the bycatch generated from traditional shrimp trawlers fishing (bottom trawl nets) for one year from September 2021 to September 2022 in Bushehr offshore (Delwar to Helle fishing grounds) at three depth layers. In the present study,75 fish species with no commercial and economic values were identified as bycatch and discards from three studied regions off Bushehr waters at different depths. The non-selective rate of this fishing method in the studied area is due to several reasons including the high biodiversity of aquatic fauna, small and non-standard of the codend mesh size, and the absence of bycatch reduction devices (BRD) in the trawl nets (Thomas *et al.,* 2017). Moreover, the high diversity of aquatic species has been similarly reported in trawl fishing in the Persian Gulf (Valinassab *et al.*, 2006a; Paighambari and Daliri, 2012; Eskandari *et al.,* 2016; Sabet *et al.,* 2018). Eighani and Paighambari (2013) demonstrated that the discards from shrimp trawlers in Hormuzgan coasts, Persian Gulf, consisted of 38 aquatic animals, which was constituted 70% of the total catch. Similar to our results a high content of discards was reported in Bushehr fishing grounds by Paighambari *et al*. (2017), who pointed out 93.48% bycatch (80.81% discards of the total bycatch; 50 aquatic groups) from total catch of the shrimp trawlers at the shallow waters up to 30 m depths. Also, a wide range of non-target aquatic species caught in other tropical regions of the world by trawlers. For instance, the trawl discard catch in the northwestern coastal areas of India included 62 aquatic species belonging to 29 families (Azeez *et al.,* 2021). In another study, Mendo *et al*. (2022) investigated the discards of shrimp trawlers in Peru and reported that a total of 246 species were discarded, including all macroalgae species (100%), 93.8% of echinoderms, tapeworms, of and molluscs, 88.2% of crustaceans, and 81.1% of small fish species. Zacharia *et al*. (2006) recorded 53 fish species as the discard caught from bottom trawlers along the coast of Karnataka (India), however, Dineshbabu *et al*. (2010) reported 116 ichthyo-fauna as the discards from the trawlers in the same area. Therefore, the quantity and composition of discard catch in one area can change over time due to different species diversity, fishing methods, duration and depth of trawling, and environmental conditions (Kodeeswaran *et al.,* 2020). In this study, the bycatch composition and CPUA were like other researches in tropical and subtropical regions with a wide range of aquatic organisms like teleost and cartilaginous fish. In this regard, gilded goatfish with the highest abundance followed by

Japanese threadfin bream (202.8 kg/nm^2) of the total bycatch. The maximum abundance of gilded goatfish is probably due to the suitable ecological and geological conditions of the regions. These fish are commonly found in mud beds at various depths (10 to 200 meters) depending on the species (Uiblein, 2007). These ecological conditions exist on Bushehr offshore, away from the coastlines towards the beginning of the continental slope, where there is no rocky and sandy bed. The maximum CPUA of gilded goatfish (265.3 kg/nm^2) in deep waters (21-30 m) in this study confirms the high presence of the fish in depths with soft and muddy substrates. In this regard, Uiblein (2007) stated that goatfish can be an indicator of ecological areas with muddy beds. In fact, most of the goatfish species move to deep layers of seawaters immediately after metamorphosis and the development of their barbels (McCormick, 1993; Shand, 1997). However, some species may remain immature in open water (McCormick and Milicich, 1993) or even feed on plankton in later ontogenetic stages (Krajewski *et al.*, 2006), but most of them are benthic (Uiblein, 2007). Therefore, 100% occurrence index of fifteen fish species in the bycatch of the studied regions at different depths can explain a wide distribution of them in Bushehr offshore due to the suitable ecological conditions. However, Paighambari and Daliri (2012) reported that ponyfish were dominant in the discards from shrimp trawling in Bushehr waters including the northern (Imam Hassan and Rig port), center (Bushehr and Tangistan), and southern (Motaf, Deir, and Taheri) parts during 2001-2002 and goatfish had a low share of the discards (1.6-5.8 CPUA), which was significantly lower than the results of this study. On the contrary, Sabet *et al*. (2018) found the highest frequency and CPUA of clupeids (*Ilisha megaloptera*) regarding shrimp trawl fishing efforts in Bushehr offshore (around Mataf Island). The difference in the discard composition in the area in previous research is probably attributed to the season, fishing grounds, and trawling methods, although it is not unlikely that an ecological shift has been occurred in the study area during these 20 years. Meanwhile, ecological shifts have been reported in different regions of the world, for instance, the data from trawlers in the Carpentaria Gulf (Australia) showed the balance between the demersal and pelagic fish has been changed over a 20-year with a decrease in the abundance of demersal fish and an increase in the abundance of pelagic fish (Clucas, 1997). Ponyfish are abundant in shallow coastal waters, intertidal areas, and estuaries (Seah *et al.*, 2009; Nelson *et al.*, 2016) and therefore, another possible reason of the reduction of ponyfish in the discard composition of Bushehr offshore is due to overfishing in the coastal waters for their human consumption (e.g., the striped ponyfish; *Aurigequula fasciata*). However, more research in this area are needed to clarify the main reasons of these changes in the discards generated by shrimp trawlers in the Persian Gulf in the future.

Chondrichthyes are dominant in the northwestern region of the Persian Gulf and they are accounted for a large amount of discards in the trawl nets (Paighambari and Daliri, 2012; Niamaimandi *et al.*, 2018). In the present study, rays with a slight difference after the gilded goatfish and Japanese threadfin bream had the highest amount of CPUA (142.18 kg/nm^2) in different sampling areas and their density and biomass were increased in the deep waters.

In similar research, Gulf whipray (*Himantura randalli*; Dasyatidae) was discarded from gillnet and trawl fisheries in the shallow waters of the Persian Gulf (Last *et al.*, 2012). According to the passive behavior of rays in the mouth of bottom trawl gear, they can enter to the codend with no swimming or other activity (Queirolo *et al.*, 2012). However, making some modifications at the footrope can be effective to reduce the discards, especially for passive species like rays (Fakıoğlu *et al.*, 2022).

In this study, the species abundance of bycatch was variable at different water depths and the highest value was related to deep waters (21-30 m) and the lowest value was observed at the shallow depths (up to 10 m). Paighambari *et al*. (2017) and Niamaimandi *et al*. (2018) reported a greater distribution of bycatch species at the mid-water stratum (20-30 m), which contradicts our results. This difference could be attributed to the high abundance of rays in the coastal waters of the studied area. In the research that has been done so far, sampling and determining discards from bottom trawlers by different water classes has rarely been done, and in order to be able to compare and draw more favorable conclusions more studies are needed in the area.

In conclusion, increasing fishing pressure on aquatic animals that have no commercial and economic values can lead to disrupt the ecosystem balance in different marine food chains. Therefore, continuous monitoring of bycatch from traditional fishing vessels in a particular area is essential in fisheries management. In the current study, the bycatch composition showed that fish (teleost and cartilaginous groups) had the largest share in the discarded fish species (78%) from the traditional shrimp trawlers in Bushehr fishing grounds, Persian Gulf. In this study, the abundance of identified fish species varied in different depths, and the highest total bycatch were related to deep water (21-30 m; 44% of the total bycatch) and the lowest value was in the shallow depths (up to 10 m; 21.7% of the total bycatch).middle depths (11-20 m; 34% of the total bycatch). In the present study, gilded goatfish with the highest frequency (433.9 kg/nm^2 and 100% occurrence rate at all depth layers) along with Japanese threadfin bream, and rays accounted for 33.7% of the total catch bycatch in the studied regions in Bushehr offshore. According to the distribution map by ArcGIS software, the density and biomass of the bycatch were increased by moving toward the west of the Persian Gulf.

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