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Diversity of flora and fauna in low-value bycatch from bottom trawls in Palk Bay, south-east coast of India

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Abstract

Palk Bay is a highly stressed ecosystem due to intense trawling activities and standard operating procedures for trawlers along this coast are an immediate requirement. To support this, the diversity and biomass of low-value bycatch (LVB) from shrimp trawls operated on the Palk Bay coast of Tamil Nadu were studied. Following multistage stratified random sampling technique, samples were collected from Rameshwaram, Mandapam and Jagathapattinam landing centres. Palk Bay's LVB contained 181 species from 142 genera, with 156 species recorded from Rameshwaram, while Mandapam and Jagathapattinam recorded 77 and 129 species, respectively. Teleosts were the most abundant (45.9%), followed by crabs (16%) and shrimp (6%). Commercial landings peaked in January, while LVB landings peaked in June and July. The LVB/target group ratio ranged from 1.75 to 3.5, implying that the target group catch is increasing while LVB landings in Palk Bay are stable. An increase in LVB harvesting will cause ecological instability, depleting fisheries resources and unbalancing the functioning of the marine ecosystem. The findings of this study are important inputs for multi-species/multi-gear tropical fisheries management. There are attempts to certify the green tiger shrimp trawl fishery in Palk Bay and therefore, diversity studies will support formulation of strategies for ecosystem-based fisheries management.

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Introduction

The Palk Bay is located between Tamil Nadu (India) and Sri Lanka along the east coast of India. The coast stretches from Dhanushkodi to Kodiakkarai, including five coastal districts: Ramanathapuram, Pudukkottai, Thanjavur, Thiruvarur and Nagapattinam. The major fishing methods used for exploiting fishery resources in Palk Bay are trawl, country trawl (mini trawl, locally called "Thallumadi or Thalluvalai") and various types of gillnets. Over 2,500 mechanised trawlers, 6,000 motorised crafts and 1,000 non-motorised crafts are operated in the Palk Bay. The most efficient fishing technique for harvesting shrimp resources is bottom trawling, but its intensity has adverse effects on benthic ecology and biodiversity (Dayton *et al*., 1995).

The terminology and definitions used in this manuscript follow Costa *et al*. (2008). Total catch is the quantity of all species brought onboard; target catch denotes the species towards which the fishing effort is directed (target species); retained (or landed); catch is part of the total catch that has economic value (*i.e.,* the quantity of target and bycatch which is being marketed) and total bycatch is the portion of the total catch that includes all the species caught accidentally (non-target species). Total bycatch may be retained if it has commercial value and it is denoted as low-value bycatch (LVB). Most of the LVB is brought to the landing centre for fishmeal, whereas the plant biota (seagrass and seaweed) are discarded onshore (Ranjith *et al*., 2018).

Earlier studies in India have documented information on trawl bycatch (Gordon, 1991; Sujatha, 1995; 1996; 2005; Pravin and Manoharadoss, 1996; Pillai, 1998; Rao, 1998; Kurup *et al*., 2003; 2004; Dixitulu, 2004; Jagadis *et al*., 2004; Bijukumar and Deepthi, 2006; 2009; Zacharia *et al*., 2006; Pillai *et al*., 2014); however, there is limited information on trawl bycatch in Palk Bay. Sivadas *et al*. (2019) stated that Palk Bay is a highly pressurised ecosystem due to trawl operations and there is an immediate need to develop standard operating procedures (SOP) for trawlers along the coast. Information on the composition and quantity of the non-target biomass from the commercial trawl fisheries in the Gulf of Mannar and Palk Bay have been documented by James and Adolf (1965); Pillai and Dorairaj (1985); Jayasankar (2003; 2006); Jagadis *et al*. (2004). But these studies were not focused on the impact of trawlers on the ecosystem. The present study documents the diversity and species composition of low-value bycatch in shrimp trawls and also estimates the quantum of low-value bycatch landed by commercial bottom trawls along the Palk Bay coast, for deriving fishery management tools.

Materials and methods

Description of the study area

Palk Bay stretches for 294 km from Dhanushkodi (9.150296 N: 79.44915 E) in Ramanathapuram District to Kodiyakarai or Point Calimere (10.2884 N: 79.86974 E) in Nagapattinam District (Fig. 1). The bay's width ranges from 64 to 137 km (Cathcart, 2003). Palk Bay supports several ecosystems, including coral reefs, seagrass, mangroves and seaweeds. The diversity and catch composition of LVB of trawl landings were studied from the selected landing centres (Rameshwaram, Mandapam and Jagathapattinam) in Palk Bay from January 2017 to December 2019. Throughout the year, mechanised trawlers (made of wood) with overall lengths (OAL) 13 to 18 m and 180 HP engines are used for penaeid shrimps. The cod-end mesh size of trawl nets is 25 mm. The fishing grounds are to the north-eastern side, all the way up to the Indian EEZ. Fishing is done day and night through six hauls per day, each lasting three hours. The average fishing trip lasts 18 to 22 h. Trawl fishing is permitted on three fishing days per week (Monday, Wednesday and Saturday), according to an agreement signed by the fishermen (Sivadas *et al.,* 2019).

Sampling and taxonomical identification of LVB

Rameshwaram, Mandapam, Soliyakudi, Jagathapattinam, Kottaipattinam, Sethubavachatram and Mallipattinam are the seven major trawl fish landing centres in Palk Bay, with major landing in Rameshwaram, Mandapam, Jagathapattinam and Kottaipattinam. The trawlers of Jagathapattinam and Kottaipattinam fish in the same grounds, but their operating levels are different. For the current study, LVB samples were collected fortnightly from three landing centres (Rameshwaram, Mandapam and Jagathapattinam) (Fig. 1). The total catch and species composition of the commercial catch was recorded at the landing centres. A multistage stratified random sampling method was used to collect the LVB sub-samples (5 kg per sampling day) (Srinath *et al*., 2005). The LVB samples were transported in ice to the laboratory for qualitative and quantitative analyses. Fischer and Bianchi (1984), Roper *et al*. (1984) and Appeltans *et al*. (2011) were followed to identify the finfish to the species level and the taxonomic information for crustaceans was verified using Froese and Pauly (2011). Chhapghar (1957), Sakai (1976), Galil and Clark (1994); Galil (1997) and Ng *et al*. (2008) were also consulted for brachyuran crabs, Holthuis (1980), Perez Farfante *et al.* (1997) for shrimps and Ahyong (2001) for stomatopods.

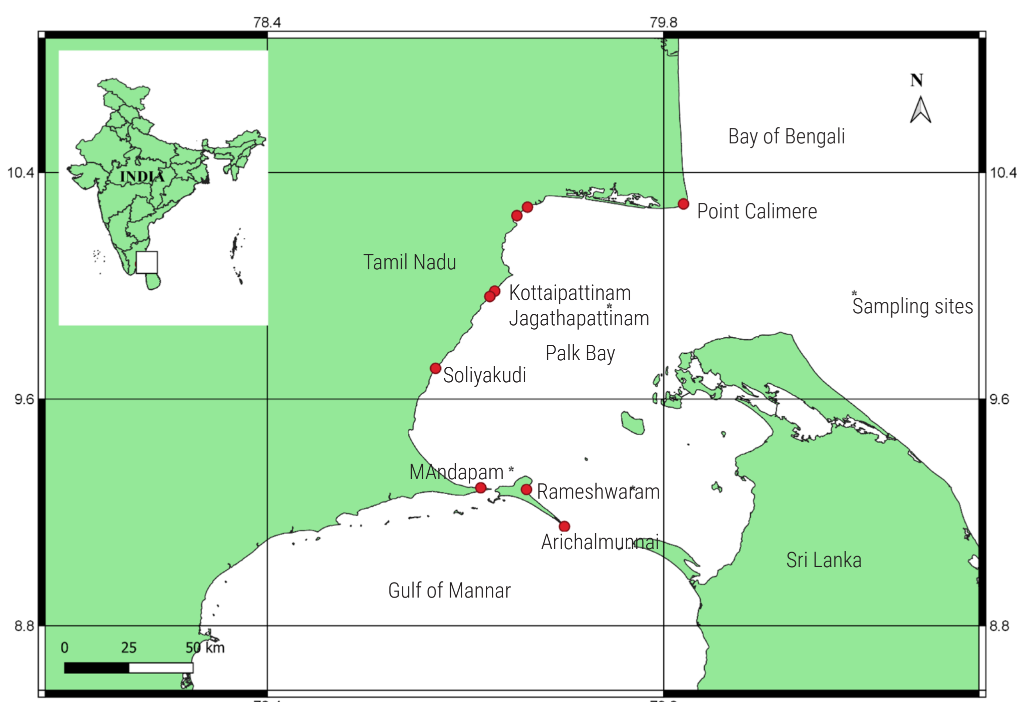

Fig. 1. Sampling locations of trawl low-value bycatch along the Palk Bay coast of Tamil Nadu

Catch estimation

Each specimen was weighed (to the nearest 0.1 g) using an electronic balance and details entered in Microsoft Excel database. Individual weight of each species in the sub-sample was raised to the total LVB from the single boat. Similarly, the LVB of the individual boat was raised to the total LVB of the days' landings. The monthly catch was obtained by multiplying the daily catch with the number of fishing days in the month.

Statistical analysis

PRIMER-7 software was used to perform univariate analysis of monthly trawl landing data for species diversity, species richness and evenness. To assess the relative abundance and evenness of species diversity, the Shannon-Weiner diversity index (H) and Pielou's evenness index (J), as well as species richness (d), were used.

Results and discussion

Species composition

The Palk Bay shrimp fishery targets the single species *Penaeus semisulcatus*. Along with *P. semisulcatus*, fish and crabs are caught as bycatch. Fishing is done throughout the year, with the peak seasons being June-July and January-February. The species in the LVB are utilised for fish meal production. This study found 156 species in the LVB from Rameshwaram, 129 in Jagathapattinam and 77 in Mandapam (Table 1). In total, 181 species belonging to 142 genera were recorded in the landings of LVB in Palk Bay. These species were represented by 45 orders and 97 families (Fig. 2). The major fifteen species constituting the LVB were *Portunus (Xiphonectes) hastoides, Eubleekeria jonesi, Leiognathus dussumieri L. brevirostris, Secutor ruconius, Alepes djedaba, L. lineolatus, Megokris granulosus, Amblygaster clupeoides, Parapenaeopsis maxillipedo, Metapenaeopsis stridulans, Stolephorus indicus, Bregmaceros mcclellandi, Cloridopsis immaculate* and *Terapon jarbua*.

Teleosts (45.9%), crabs (16%), shrimps (6.1%), lobsters (0.6%), gastropods (8.3%), stomatopods (2.8%), bivalves (7.2%), cuttlefish (1.7%), squids (1.1%), octopus (0.6%), seaweeds (1.7%) and sea urchins (1.1%) were the major groups that comprised the LVB. Teleosts had the most families (45.4%), followed by gastropods (13.4%), crabs (12.4%), bivalves (9.3%), seaweeds (3.1%) and shrimps (2.1%). Among different Orders, teleosts (26.7%) had the highest percentage, followed by bivalves (15.6%), gastropods (11.1%) and seaweeds (6.7%) (Fig. 4).

Peak commercial landings were observed in January (Fig. 3) and peak LVB landings were observed in June-July. Tamil Nadu has imposed a monsoon trawl ban from 15 April to 15 June *vide* G.O.No.119, Animal Husbandry, Dairying and Fisheries Department (FS.3), Government of India. dated 25.05.2017. The LVB were sold to the fishmeal industry and <5% of the total catch is discarded. The ratio of LVB landings to target group landings in Palk Bay was recorded as 1:1.75 in Rameshwaram, 1:2.86 in Mandapam and 1:3.5 in Jagathapattinam. This suggests that while LVB landings remain relatively stable, the catch from the target group is on the rise.

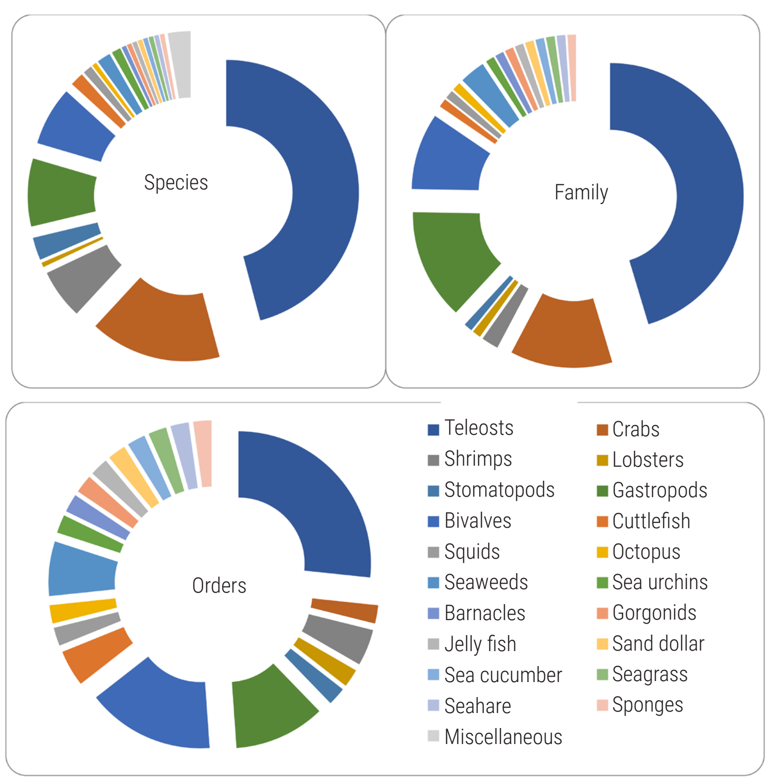

Fig. 2. Percentage contribution of species, family and orders recorded in low-value bycatch in shrimp trawl

Table 1. List of species recorded in trawl low-value bycatch (LVB) off Palk Bay

Sl. No.	Species	Order	Family	Size range (mm)	Species abundance in fish landing centre			Average biomass (kg)	Biomass (%)
					Rameshwaram	Mandapam	Jagathapattinam		
Teleost									
1	*Acanthurus mata*	Perciformes	Acanthuridae	60-153	+	-	-	3189	0.29
2	*Apogon queketti*		Apogonidae	25-53	+	+	-	5566	0.51
3	*Apogonichthyoides nigripinnis*			25-60	+	-	+	5251	0.48
4	*Apogonichthyoides pseudotaeniatus*			27-59	-	+	-	308	0.03
5	*Ostorhinchus fasciatus*			25-49	+	+	+	10077	0.93
6	*Pristiapogon fraenatus*			24-56	+	-	-	2326	0.21
7	*Pterocaesio chrysozona*		Caesionidae	42-62	+	-	-	2687	0.25
8	*Alepes djedaba*		Carangidae	53-135	+	+	+	57533	5.31
9	*Alepes kleinii*			55-142	+	-	+	19893	1.84
10	*Decapterus russelli*			64-130	+	-	-	7795	0.72
11	*Selaroides leptolepis*			29-56	+	-	+	17455	1.61
12	*Platax orbicularis*		Ephippidae	55-90	+	-	-	2281	0.21
13	*Platax teira*			45-69	+	-	+	1889	0.17
14	*Gerres filamentosus*		Gerreidae	50-130	+	-	-	4226	0.39
15	*Gerres oblongus*			52-132	+	+	+	8490	0.78
16	*Gerres oyena*			49-130	+	-	+	8227	0.76
17	*Parachaeturichthys polynema*		Gobiidae	26-65	+	+	+	4593	0.42
18	*Eubleekeria jonesi*		Leiognathidae	20-85	+	+	+	117839	10.87
19	*Gazza minuta*			19-63	+	-	-	3279	0.30
20	*Leiognathus brevirostris*			25-65	+	-	+	70453	6.50
21	*Leiognathus bindus*			60-70	+	+	+	91919	8.48
22	*Leiognathus lineolatus*			56-69	+	-	+	36276	3.35
23	*Leiognathus equulus*			19-60	+	-	+	1243	0.11
24	*Secutor insidiator*			25-42	+	-	+	4711	0.43
25	*Secutor ruconius*			19-45	+	+	+	45535	4.20
26	*Lethrinus lentjan*		Lethrinidae	57-162	+	-	-	309	0.03
27	*Lutjanus fulvus*		Lutjanidae	47-163	+	-	-	3839	0.35
28	*Upeneus sundaicus*		Mullidae	39-69	-	-	+	451	0.04
29	*Upeneus tragula*			30-65	+	+	+	7729	0.71
30	*Nemipterus bipunctatus*		Nemipteridae	55-90	+	-	-	609	0.06
31	*Nemipterus zysron*			55-95	+	-	-	2796	0.26
32	*Parapercis pulchella*		Pinguipedidae	56-110	+	-	-	3266	0.30
33	*Johnius amblycephalus*		Sciaenidae	40-67	+	-	-	564	0.05
34	*Johnius carutta*			40-75	+	-	-	6669	0.62
35	*Kathala axillaris*			55-90	+	-	+	7933	0.73
36	*Otolithes ruber*			52-119	+	+	+	7189	0.66
37	*Katsuwonus pelamis*		Scombridae	290-530	+	-	-	7119	0.66
38	*Rastrelliger kanagurta*			46-78	+	-	-	2590	0.24
39	*Scomberomorus commerson*			150-210	+	-	-	7145	0.66
40	*Sillago sihama*		Sillaginidae	35-86	+	-	+	2770	0.26
41	*Sphyraena obtusata*		Sphyraenidae	78-120	+	-	-	839	0.08
42	*Terapon jarbua*		Terapontidae	36-67	+	+	+	95404	8.80
43	*Terapon puta*			36-69	+	-	-	9677	0.89
44	*Lepturacanthus savala*		Trichiuridae	100-180	+	-	+	2268	0.21
45	*Trichiurus lepturus*			110-160	-	+	+	3435	0.32
46	*Uranoscopus marmoratus*		Uranoscopidae	68-170	+	-	-	20655	1.91

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47	*Pellona ditchela*	Clupeiformes	Pristigasteridae	39-70	+	+	+	17022	1.57
48	*Amblygaster clupeoides*		Clupeidae	42-96	+	-	+	20621	1.90
49	*Hilsa kelee*			56-123	+	+	+	9100	0.84
50	*Sardinella albella*			25-70	+	-	+	38075	3.51
51	*Sardinella gibbosa*			22-70	+	+	+	50398	4.65
52	*Sardinella longiceps*			90-120	+	-	+	2139	0.20
53	*Dussumieria acuta*		Dussumieriidae	52-120	+	-	+	953	0.09
54	*Stolephorus indicus*		Engraulidae	25-54	+	+	+	21870	2.02
55	*Thryssa mystax*			34-58	+	-	+	8713	0.80
56	*Fistularia commersonii*	Syngnathiformes	Fistulariidae	215-560	+	-	-	348	0.03
57	*Fistularia petimba*			214-590	+	-	+	90	0.01
58	*Hippocampus kuda*		Syngnathidae	36-55	+	+	+	372	0.03
59	*Syngnathoides biaculeatus*			70-160	+	-	-	268	0.02
60	*Gymnothorax reticularis*	Anguilliformes	Muraenidae	250-690	+	-	-	1965	0.18
61	*Ariosoma anago*		Congridae	136-200	+	-	+	3144	0.29
62	*Arius arius*	Siluriformes	Ariidae	70-151	+	+	+	7761	0.72
63	*Plotosus lineatus*		Plotosidae	39-95	+	-	-	2504	0.23
64	*Bregmaceros mcclellandi*	Gadiformes	Bregmacerotidae	20-55	+	-	+	12660	1.17
65	*Arothron immaculatus*	Tetraodontiformes	Tetraodontidae	50-105	+	+	+	8014	0.74
66	*Lagocephalus lunaris*			52-90	+	+	-	548	0.05
67	*Triacanthus biaculeatus*		Triacanthidae	36-78	-	-	+	3113	0.29
68	*Aluterus monoceros*		Monacanthidae	40-62	+	-	-	7959	0.73
69	*Anacanthus barbatus*			62-95	+	-	+	1624	0.15
70	*Aluterus scriptus*			34-142	+	-	+	8395	0.77
71	*Rhynchostracionnasus*		Ostraciidae	45-65	+	-	+	3587	0.33
72	*Pseudorhombus arsius*	Pleuronectiformes	Paralichthyidae	49-78	+	+	+	26322	2.43
73	*Pseudorhombus oculocirris*			45-70	+	+	+	4436	0.41
74	*Zebrias synapturoides*		Soleidae	42-65	+	+	+	9260	0.85
75	*Psettodes erumei*		Psettodidae	60-82	+	-	-	7524	0.69
76	*Cynoglosus arel*		Cynoglossidae	52-106	+	-	+	20416	1.88
77	*Pegasus volitans*	Gasterosteiformes	Pegasidae	53-89	+	-	+	715	0.07
78	*Platycephalus indicus*	Scorpaeniformes	Platycephalidae	52-90	+	+	+	25677	2.37
79	*Kumococius rodericensis*			42-110	+	+	+	27432	2.53
80	*Pterois miles*		Scorpaenidae	60-88	-	-	+	515	0.05
81	*Chauliodus sloani*	Stomiiformes	Stomiidae	80-209	+	-	-	999	0.09
82	*Saurida tumbil*	Aulopiformes	Synodontidae	68-120	+	-	+	237	0.02
83	*Trachinocephalus myops*			68-125	+	-	-	2789	0.26
	Subtotal				78	26	52	1083859	100.00
Crabs									
84	*Aethra scruposa*	Decapoda	Aethridae	26-35	-	-	+	234	0.04
85	*Calappa bilineata*		Calappidae	39-85	-	+	-	2895	0.56
86	*Dorippe frascone*		Dorippidae	51-75	+	+	+	11595	2.23
87	*Dorippe quadridens*			40-69	+	-	-	5006	0.96
88	*Dorippoides facchino*			45-74	+	+	+	25507	4.90
89	*Doclea alcocki*		Epialtidae	14-20	-	-	+	451	0.09
90	*Doclea ovis*			25-52	+	+	+	2966	0.57
91	*Eucrate alcocki*		Euryplacidae	20-32	+	-	+	5302	1.02
92	*Galene bispinosa*		Galenidae	38-139	+	+	+	76742	14.73
93	*Halimede ochtodes*			40-95	+	+	+	2232	0.43
94	*Arcania erinacea*		Leucosiidae	15-20	+	+	+	1629	0.31
95	*Arcania heptacantha*			14-19	+	+	+	4973	0.95
96	*Ixa cylindrus*			46-52	-	-	+	111	0.02

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97	*Leucosia anatum*	Decapoda		14-19	+	+	+	10737	2.06
98	*Leucosia rubripalma*			14-21	+	-	-	760	0.15
99	*Matuta planipes*		Matutidae	28-56	-	-	+	8949	1.72
100	*Pylopaguropsis magnimanus*		Paguridae	20-24	+	+	+	6518	1.25
101	*Enoplolambrus echinatus*		Parthenopidae	20-39	+	-	-	3181	0.61
102	*Charybdis (Charybdis) annulata*		Portunidae	35-90	+	-	+	10043	1.93
103	*Charybdis (Charybdis) feriata*			42-54	+	-	-	1964	0.38
104	*Charybdis (Charybdis) granulata*			41-56	+	-	-	13449	2.58
105	*Charybdis (Charybdis) natator*			45-99	+	+	+	10804	2.07
106	*Portunus (Monomia) gladiator*			25-58	+	+	+	9311	1.79
107	*Portunus (Lupocycloporus) gracilimanus*			25-55	+	+	+	4182	0.80
108	*Portunus (Xiphonectes) hastoides*			13-40	+	+	+	180131	34.59
109	*Portunus pelagicus*			30-120	+	+	+	10089	1.94
110	*Portunus sanguinolentus*			35-105	+	+	+	7978	1.53
111	*Thalamita crenata*			19-45	+	+	+	65407	12.56
112	*Scalopidia spinosipes*		Scalopidiidae	19-25	+	+	+	37687	7.24
	Subtotal				24	18	23	520833	100.00
Shrimps									
113	*Alpheus lobidens*	Decapoda	Alpheidae	40-132	+	+	+	3872	5.77
114	*Parapenaeopsis maxillipedo*		Penaeidae	38-68	+	+	+	16702	24.88
115	*Megokris granulosus*			45-94	+	+	+	21398	31.88
116	*Metapenaeopsis stridulans*			37-85	+	+	+	11008	16.40
117	*Metapenaeopsis toloensis*			39-89	-	-	+	6120	9.12
118	*Metapenaeus lysianassa*			33-80	-	+	+	3527	5.25
119	*Metapenaeus moyebi*			36-87	+	+	+	1830	2.73
120	*Parapenaeopsis acclivirostris*			30-63	+	-	-	249	0.37
121	*Parapenaeopsis stylifera*			45-96	+	-	+	422	0.63
122	*Penaeus latisulcatus*			50-115	-	-	+	580	0.86
123	*Penaeus semisulcatus*			49-120	+	+	+	1423	2.12
	Subtotal				8	7	10	67131	100.00
Lobsters									
124	*Petrarctus rugosus*	Decapoda	Scyllaridae	30-56	-	+	-	227	100.00
	Subtotal				0	1	0		
Stomatopods									
125	*Cloridopsis immaculata*	Stomatopoda	Squillidae	35-107	+	+	+	100324	38.99
126	*Erugosquilla woodmasoni*			30-115	+	+	+	12010	4.67
127	*Harpiosquilla annandalei*			40-120	+	-	-	34272	13.32
128	*Harpiosquilla harpax*			55-200	+	-	-	11390	4.43
129	*Oratosquilla oratoria*			50-155	+	+	+	99329	38.60
	Subtotal				5	3	3	257325	100.00
Cephalopods									
130	*Amphioctopus aegina*	Octopoda	Octopodidae	40-51	+	-	+	1401	4.49
131	*Sepioteuthis lessoniana*	Myopsida	Loliginidae	27-60	-	-	+	1239	3.97
132	*Uroteuthis (Photololigo) duvaucelii*			29-60	+	-	+	541	1.74

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133	*Sepia aculeata*	Sepiida	Sepiidae	20-34	+	-	+	1301	4.17
134	*Sepiella inermis*			20-26	+	-	+	3476	11.14
135	*Euprymna scolopes*		Sepiolidae	14-19	+	+	+	20049	64.29
	Subtotal				5	1	6	31188	100.00
Gastropods									
136	*Hydatina zonata*	Heterobranchia (sub class)	Aplustridae	20-38	+	+	+	2969	3.27
137	*Bursa spinosa*	Littorinimorpha	Bursidae	52-81	+	+	-	363	0.40
138	*Semicassis bisulcata*		Cassidae	25-80	+	-	-	629	0.69
139	*Lotoria lotoria*		Cymatiidae	50-90	+	+	-	5921	6.53
140	*Ficus ficus*		Ficidae	16-65	+	+	-	570	0.63
141	*Natica vittellus*		Naticidae	20-25	-	-	+	3829	4.22
142	*Tanea lineata*			20-30	-	+	+	3800	4.19
143	*Tonna dolium*		Tonnidae	80-150	-	+	-	3085	3.40
144	*Conus amadis*	Neogastropoda	Conidae	25-55	+	+	-	2199	2.43
145	*Chicoreus ramosus*		Muricidae	50-80	+	-	+	2281	2.52
146	*Murex carbonnieri*			70-90	+	+	+	48012	52.95
147	*Babylonia zeylanica*		Babyloniidae	18-61	+	+	+	5403	5.96
148	*Melo melo*		Volutidae	52-90	-	-	+	7473	8.24
149	*Euchelus asper*	Trochida	Trochidae	04-28	+	+	+	429	0.47
150	*Turritella attenuata*	Caenogastropoda	Turritellidae	35-99	+	+	-	2271	2.50
151	*Aplysia fasciata*	Aplysiida	Aplysiidae	25-36	+	-	-	1437	1.58
	subtotal				12	11	8	90671	100.00
Bivalves									
152	*Anadara formosa*	Arcida	Arcidae	23-29	+	+	+	17002	14.09
153	*Vepricardium asiaticum*	Cardiida	Cardiidae	30-42	+	+	+	24708	20.47
154	*Donax cuneatus*		Donacidae	20-25	+	-	+	5849	4.85
155	*Brachidontes esmeraldensis*	Mytilida	Mytilidae	25-30	+	-	+	5735	4.75
156	*Pinna bicolor*	Ostreida	Pinnidae	90-200	+	-	+	1902	1.58
157	*Saccostrea cuccullata*		Ostreidae	30-42	+	-	+	1301	1.08
158	*Aequipecten opercularis*	Pectinida	Pectinidae	20-52	-	-	+	1031	0.85
159	*Mimachlamys crassicostata*			28-32	+	-	+	1351	1.12
160	*Placuna placenta*		Placunidae	40-70	+	+	+	25761	21.35
161	*Gafrarium pectinatum*	Venerida	Veneridae	20-25	+	-	+	683	0.57
162	*Paphia textile*			23-45	+	-	+	409	0.34
163	*Paratapes undulatus*			20-45	+	+	+	6198	5.14
164	*Circe scripta*			15-20	-	-	+	528	0.44
165	*Marcia opima*			15-30	+	-	+	28225	23.39
	Subtotal				11	4	8	120682	100.00
Gorgonids									
166	*Annella reticulata*	Alcyonacea	Gorgoniidae	80-250	+	+	+	2668	100.00
	Subtotal				1	1	1	2668	100.00
Echinoderms									
167	*Echinodiscus auritus*	Clypeasteroida	Astriclypeidae	20-60	+	-	-	842	4.80
168	*Holothuria (Theelothuria) spinifera*	Holothuriida	Holothuriidae	90-130	+	-	-	1372	7.82
169	*Salmacis virgulata*	Camarodonta	Temnopleuridae	40-70	-	-	+	1646	9.38
170	*Temnopleurus toreumaticus*			25-40	+	+	+	6198	35.31
171	*Salmaciella dussumieri*	Camarodonta	Temnopleuridae	20-40	+	+	+	4664	26.57
172	*Ophiocnemis marmorata*	Amphilepidida	Ophiotrichidae	40-70	+	+	+	2833	16.14
	Subtotal				4	1	2	17555	100.00
Seagrass									
173	*Cymodocea serrulata*	Alismatales	Cymodoceaceae	150-200	+	+	+	21187	
	Subtotal				1	1	1	21187	

Contd..................

Seaweeds									
174	*Gracilaria edulis*	Gracilariales	Gracilariaceae	50-130	-	-	+	425	31.49
175	*Sargassum wightii*	Fucales	Sargassaceae	130-200	+	-	+	676	50.10
176	*Ulva lactuca*	Ulvales	Ulvaceae	50-140	-	-	+	249	18.42
	Subtotal				1	0	3	1350	100.00
Barnacle									
177	*Balanus balanus*	Balanomorpha	Balanidae	05-25	+	-	+	6490	
	Subtotal				1	0	1		
Jellyfish									
178	*Aurelia solida*	Semaeostomeae	Ulmaridae	130-170	+	-	+	2779	
Sponges									
179	*Callyspongia clathrata*	Haplosclerida	Callyspongiidae	40-135	-	-	+	3543	
Miscellaneous									
180	Cephalopods egg mass				+	-	-	4613	10.02
181	Chank egg mass				+	+	+	5724	12.43
	Subtotal				5	3	4	46058	100.00
	Total				156	77	129		

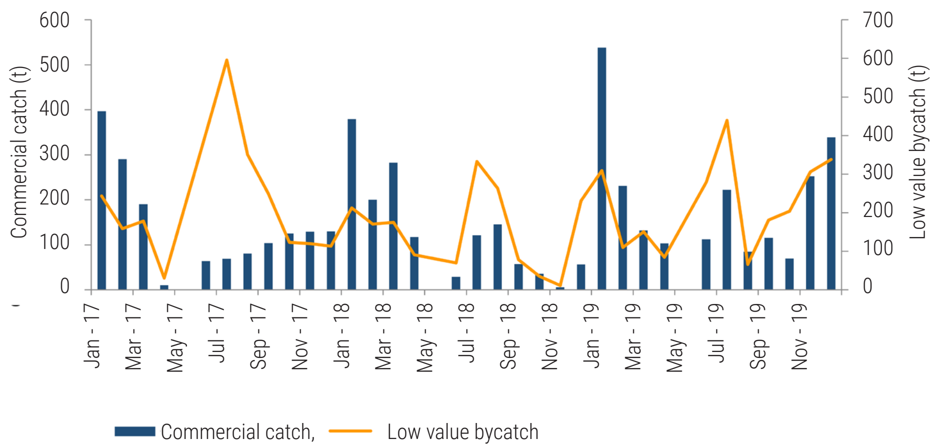

Fig. 3. Trawl landings of commercial catch and low-value bycatch Palk Bay

Fig. 4. Commercial catch and low-value bycatch onboard a trawl vessel

Trawling operations harvest over 400 different species in tropical waters (EJF, 2003). Furthermore, tropical waters have a greater diversity of discarded species from trawling than temperate waters. Prabhu *et al*. (2013) identified 84 species from Mallipattinam, Sethubavachatram and Mimisal (36 gastropods, 17 bivalves, 6 cephalopods, 13 crabs, 5 shrimp, 2 stomatopods, echinoids, asteroids and 1 scyphozoan). Pillai *et al*. (2014) discovered 64 crustacean species (37 brachyuran crabs, 1 anomuran, 16 shrimps, 2 lobsters and 8 stomatopods) from trawl landings in the Chennai Fishing Harbour. Gibinkumar *et al*. (2012) reported 281 species, including juveniles of commercially important fish and shellfish from the shrimp trawl bycatch in Cochin waters. The LVB of multiday trawlers operating off Mangalore consisted of 121 finfishes belonging to 82 genera, 55 families and 13 orders (Mahesh *et al*., 2014). Menon (1996) discovered 20 fish species, 26 crustaceans, 23 gastropod species, 15 bivalves and 10 echinoderms, polychaetes, anemones, sponges, gorgonids, ascidians, echinoids, juvenile fishes and cephalopods in trawl bycatch landings in Karnataka, Kerala and Tamil Nadu. Studies on the impact of bottom trawling on the ecology of fishing grounds and living resources in Palk Bay and the Gulf of Mannar (CMFRI, 2002) recorded 185 species caught as bycatch. Kurup *et al*. (2003) discovered 103 species of finfishes in bottom trawl discards off the Kerala coast.

Tropical shrimp fisheries have a high discard rate, accounting for more than 21% of total discards (FAO, 2004). On the Mangalore coast, Mahesh *et al*. (2017; 2019) reported that single-day trawlers landed 61.8% of their catch as edible grade and 38.2% as LVB, whereas multiday trawlers landed 79.6% as edible and the remaining 20.4% as LVB. Shrimp trawling had the highest discard/catch ratio of any fishery, ranging from about 3:1 to 15:1 and the amount of bycatch varies depending on the target species, seasons, and areas (EJF, 2003). Andrew and Pepperell (1992) estimated total global discards from shrimp fisheries as 16.7 million t. Bycatch ratios were reported as 1:4.6 and 1:1.26 in India's south-west and south-east, respectively (CMFRI, 2000). Ranjith *et al*. (2018) found that the biomass of seagrass and seaweeds dislodged in Thoothukudi waters was 63 and 37%, respectively.

Diversity indices

Rameshwaram had the highest species richness index ('d') 20.87, followed by Jagathapattinam (19.87); Mandapam had the lowest (18.05). (Table 2). As a result, the monthly variation in species richness (Table 3) was greatest in January 2019 (16.78) and lowest in September 2018 (9.52). Seasonal species richness (d) was highest (22.28) in post-monsoon of 2018 and lowest (13.18) in monsoon of 2018 (Table 4). The Shannon-Weiner diversity index (H'Log 2) was highest in Jagathapattinam (5.47) and lowest in Mandapam (4.86). (Table 2). The range of the index indicates that LVB landed at these centres is diverse. The Shannon-Weiner Index influences both the number of species and the evenness of their populations; as both increases, so does diversity. The maximum number of species (112) was recorded in March 2019, while the lowest (56) was recorded in October 2018. The Shannon-Weiner diversity index was highest in March 2019 and lowest in July 2018 (Table 2). The low H 'value in December 2018 could be attributed to the dominance of one species (*Alepes djedaba*) in the LVB. Season-wise, the Shannon-Weiner diversity was highest (5.76) in post-monsoon of 2018 and lowest (4.27) in monsoon of 2018 (Table 4).

Table 2. Diversity indices of low-value bycatch (LVB) landed at selected fish landing centres

Parameter	S	N	d	J'	Brillouin H	H'(log2)	Delta	Delta*	Delta+	Hill's diversity N1
Rameshwaram	172	3614	20.872	0.728	3.664	5.411	86.261	91.849	96.438	42.562
Mandapam	135	1670	18.057	0.687	3.251	4.867	83.286	91.043	96.525	29.199
Jagathapattinam	166	4055	19.861	0.742	3.718	5.475	87.634	92.876	96.626	44.480

S- Total species, N- Total individuals, d- Species richness, J- Pielou's Evenness index, (H'Log 2) - Shannon-Weiner diversity index

Table 3. Monthly diversity indices of low-value bycatch (LVB) landed at fish landing centres of Palk Bay from 2017 to 2019

Year	Parameter	S	N	d	J'	Brillouin H	H'(log2)	Delta	Delta*	Delta+	Hill's diversity N1
2017	Jul	78	612	11.999	0.679	2.788	4.273	83.212	93.463	95.504	19.335
	Aug	65	440	10.514	0.775	3.025	4.669	86.611	93.384	96.298	25.443
	Sep	64	363	10.688	0.795	3.059	4.774	85.467	92.902	95.572	27.367
	Oct	79	366	13.214	0.822	3.305	5.183	87.197	91.434	95.610	36.348
	Nov	79	511	12.507	0.788	3.227	4.969	84.853	89.480	95.447	31.326
	Dec	65	382	10.764	0.779	3.0173	4.694	85.749	92.938	96.598	25.901
2018	Jan	77	457	12.408	0.722	2.915	4.529	83.941	93.497	96.505	23.094
	Feb	77	620	11.820	0.684	2.800	4.290	78.774	89.194	95.856	19.574
	Mar	88	688	13.315	0.762	3.225	4.924	88.591	95.165	96.199	30.368
	Apr	65	270	11.431	0.807	3.056	4.860	86.750	92.567	96.766	29.041
	Jul	87	1361	11.918	0.603	2.596	3.888	73.911	91.837	95.629	14.814
	Aug	70	257	12.434	0.793	3.028	4.860	86.600	93.701	95.869	29.054
	Sep	67	412	10.961	0.777	3.042	4.718	87.372	94.843	96.166	26.332
	Oct	56	322	9.524	0.761	2.831	4.424	83.647	92.356	95.584	21.474
	Dec	69	317	11.807	0.787	3.048	4.807	86.470	92.780	95.684	28.006
2019	Jan	105	490	16.789	0.813	3.498	5.464	85.965	89.942	96.048	44.140
	Feb	97	506	15.417	0.783	3.327	5.170	86.991	92.145	95.956	36.016
	Mar	112	529	17.700	0.830	3.633	5.656	89.464	92.620	95.692	50.450
	Apr	99	436	16.124	0.743	3.127	4.930	83.929	93.453	96.330	30.499

Table 4. Season-wise diversity indices of low-value bycatch from fish landing centres of Palk Bay during 2017 to 2019

Parameter	S	N	d	J'	Brillouin H	H'(log2)	Delta	Delta*	Delta+	Hill's diversity N1
PrMoN 2017	101	1052	14.371	0.722	3.187	4.807	85.823	93.102	96.079	28.006
MoN 2017	131	1240	18.251	0.776	3.623	5.461	87.524	91.785	96.095	44.053
PoMoN 2017	135	1459	18.392	0.711	3.349	5.032	84.698	91.003	96.633	32.725
SuM 2018	114	958	16.460	0.771	3.472	5.269	89.159	94.326	96.495	38.565
PrMoN 2018	118	1618	15.834	0.620	2.850	4.271	76.908	91.940	96.450	19.313
MoN 2018	88	734	13.184	0.755	3.202	4.879	86.182	93.881	96.584	29.426
PoMoN 2018	161	1313	22.283	0.786	3.811	5.764	88.345	91.801	96.422	54.343
SuM 2019	155	965	22.109	0.784	3.730	5.707	88.667	92.865	96.499	52.256

In Jagathapattinam, the current study discovered a maximum evenness index (J) of 0.74, indicating that species are evenly distributed throughout the month in the LVB. Mandapam had the lowest evenness index (J) of 0.68. The month-wise evenness index (J) was high in March 2019, showing species were evenly distributed in LVB throughout the month. The highest 'd' value in Palk Bay revealed the greatest species diversity. The season-wise evenness index was highest (0.786) during the 2018 post-monsoon season and lowest (0.620) during the 2018 pre-monsoon season. The K-dominance curve was created by plotting the percentage of cumulative abundance against species rank K on a logarithmic scale. The spatial, seasonal and monthly variation in the dominance plot between the three Palk Bay landing sites revealed that Jagathapattinam had a higher cumulative relative abundance than the other two landing sites (Fig. 5). The dominance plot revealed that the curve for the month of March 2019, which was on the lower side, extended further and rose slowly due to the high density of species. The curve extends horizontally as the percentage contribution of each species is added until it reaches 100%. The plot revealed, the density of fish species and the number of species richness were higher in October 2015 (Fig. 6). The number of species collected in the current study was higher during the post-monsoon season. The cumulative relative abundance after the monsoon was higher than in other seasons, with the lowest in the 2018 monsoon (Fig. 7).

The goal of cluster analysis is to organise individuals into classes or groups so that similarities within and between groups can be examined. The dendrogram revealed that the high species richness of the Jagathapatinam and Mandapam landing centres resulted in greater similarities, whereas Rameshwaram Landing Centre formed a separate cluster (Fig. 8). Seasonal Bray-Curtis similarity coefficient and dendrogram plot revealed a high (77.16%) similarity between monsoon and post-monsoon and a low (63.16%) similarity between 2018 post-monsoon and 2019 summer (Figs. 9-11). Table 2 shows the estimated values of monthly taxonomic diversity for the three landing sites. Mandapam (83.28) Landing Centre had the lowest variation in taxonomic diversity, while the Jagathapattinam (87.63) Landing Centre had the highest variation, followed by Rameshwaram (86.26).

The taxonomic distinctness (Δ*) was found to be lowest at Mandapam and highest at the Jagathapattinam Landing Centre among the three landing sites (Table 2). The highest monthly variation in taxonomic distinctness (Δ*) was estimated in March 2018, with the lowest range (89.19) occurring in February 2018. (Table 3). The seasonal variation in taxonomic distinctness (Δ*) was estimated to be highest (94.32) in the summer of 2018 and lowest (91.00) during the post-monsoon in 2017 (Table 4). Overall, the taxonomic distinctness was lower in the post-monsoon 2017 period, with an increase in the monsoon 2018 period, followed by pre-monsoon 2017 and highest in the summer 2018 period. Seasonal differences in average taxonomic distinctness (Δ+) were estimated to be greatest (96.63) in post-monsoon 2017 and lowest (96.06) in pre-monsoon 2017. A similar pattern was found for spatial variation in average taxonomic distinctness (Δ+) (Table 4). Fig. 12 depicts the 95% confidence funnel generated for the average taxonomic distinctness index (Δ+) of all landing centres in Palk Bay. A 95% probability contours of average taxonomic distinctness (Δ+)

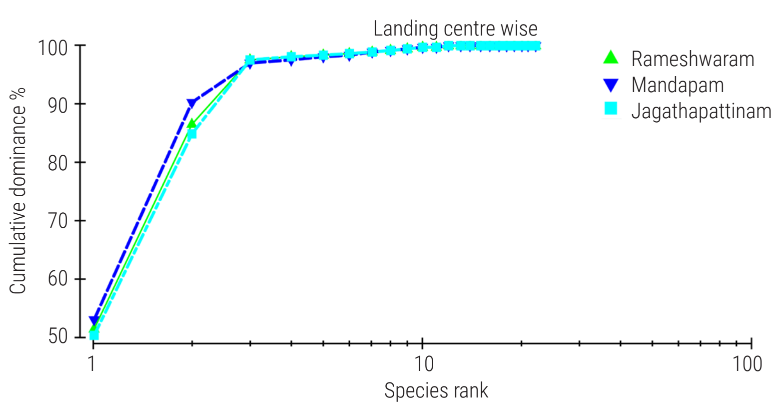

Fig. 5. Dominance plot for centre-wise trawl landings of commercial catch and low-value bycatch in Palk Bay

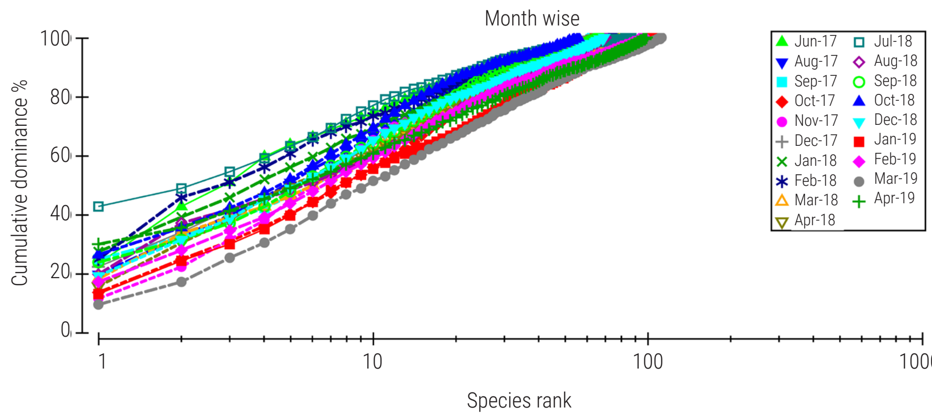

Fig. 6. Dominance plot for month-wise trawl landings of commercial catch and low-value bycatch in Palk Bay

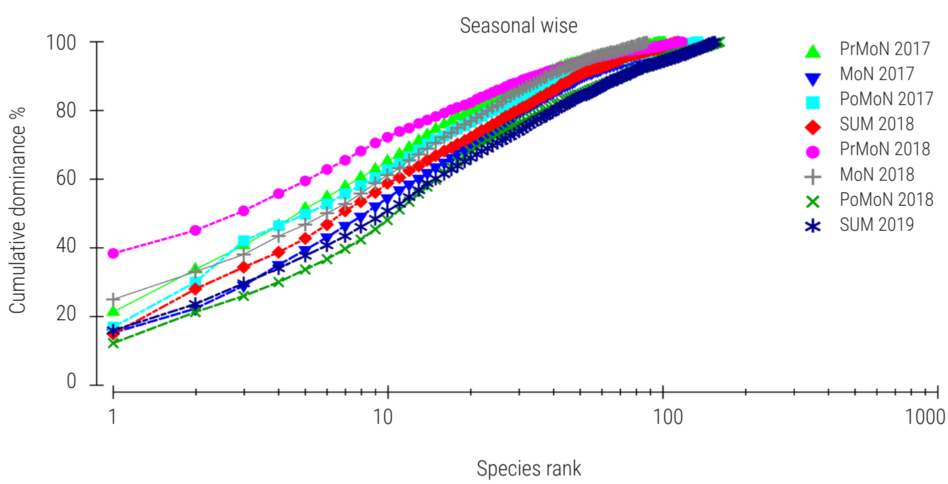

Fig. 7. Dominance plot for season-wise trawl landings of commercial catch and low-value bycatch in Palk Bay

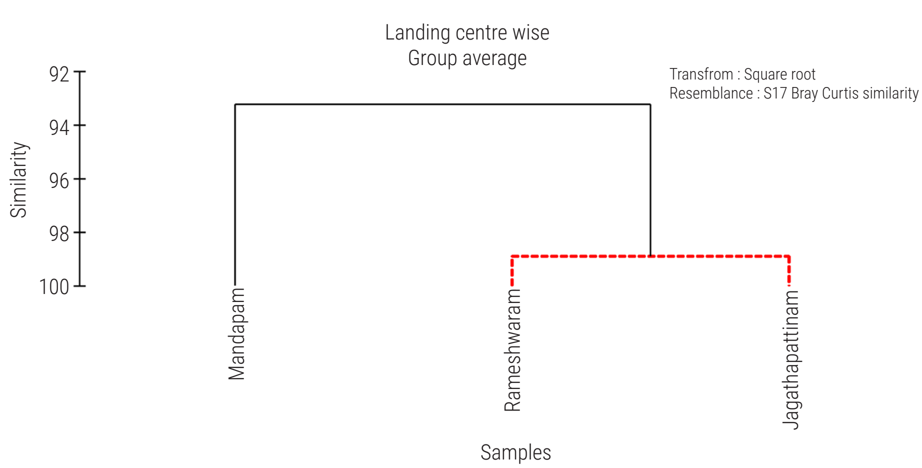

Fig. 8. Dendrogram plot for centre-wise trawl landings of commercial catch and low-value bycatch in Palk Bay

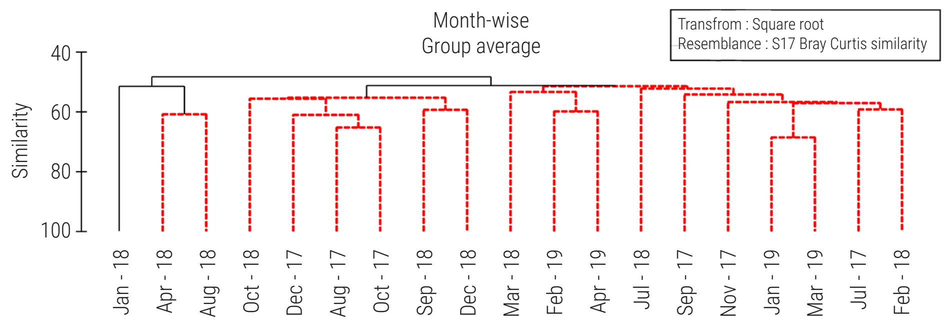

Fig. 9. Dendrogram for month-wise trawl landings of commercial catch and low-value bycatch in Palk Bay

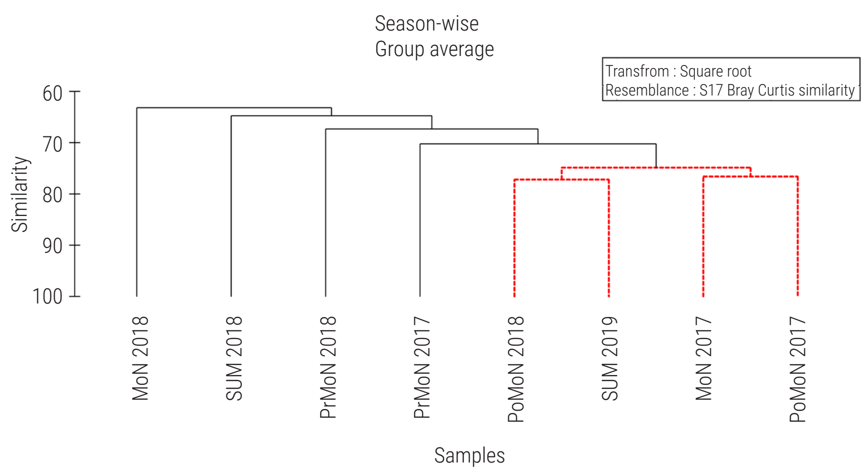

Fig. 10. Dendrogram for the trawl landings of commercial catch and low-value bycatch in Palk Bay

were fitted well outside the confidence funnel, indicating statistically significant deviations from the typical deviation in fish diversity between landing centres. For average taxonomic distinctness (Δ+) and variation in taxonomic distinctness (lambda+), the 95% confidence ellipse plot was generated. The ellipse plot of average taxonomic distinctness and variation in taxonomic distinctness values shows a statistically significant departure from the ellipse for the observations at all landing centres, as shown in Fig. 13. According to PCA analysis, the extracted principal component 1 (PC1) accounted for 52.8% of the total seasonal variability in the LVB. PC2 and PC3 showed 45.7 and 1.1% variation, respectively. Fig. 14 depicts a PCA plot for various groups of non-edible faunal biota.

Margalef's richness index ranged from 2.306 to 6.782 in the waters of Mallipattinam, Sethubavachatram and Mimisal, according to Prabhu *et al*. (2013). According to Pillai *et al*. (2014), the species richness (d) was highest (10.28) in northern Tamil Nadu waters. The Shannon-Weiner diversity indices of Mallipattinam, Sethubavachatram and Mimisal species ranged from 2.035 to 4.776, according to Prabhu *et al*. (2013). Pillai *et al*. (2014) found that the Shannon-Weiner index for Coromandel waters ranged from 4.76 to 5.59, which is consistent with the current study. Pielou's evenness index for Mallipattinam, Sethubavachatram and Mimisal ranged between 0 and 0.488, according to Prabhu *et al*. (2013). Pillai *et al*. (2014) reported that the species evenness (J) is 0.92 to 0.99 in northern Tamil Nadu waters. Similarly, Pillai *et al*. (2014) discovered that taxonomic diversity ranged between 0.488 and 0.957 in Coromandel waters. Naomi *et al*. (2011) studied fish diversity in southern Kerala using trawl nets, Karuppasamy *et al*. (2016) in Wadge Bank and Kumar *et al*. (2015) on the Mangaluru coast. They discovered that the greatest diversity of fish occurred after the monsoon season. This occurrence was linked to fish aggregation in coastal waters caused by upwelling, which is common along the west coast during the south-west monsoon (Nair and Thampy, 1980).

Palk Bay's extensive trawl fishing operation brought in many low-value species. This study shows that monsoon has a significant impact on the composition of the bycatch. The north-east monsoon, which is active along the Palk Bay coast, brings a significant nutrient load and acts as a productivity booster in these waters. As a result, any unsustainable harvesting of LVB may cause ecological instability, affecting marine organisms and depleting fishery resources. The baseline data presented in this paper could pave the way for policy measures for developing harvest control rules for sustainable shrimp trawl fishery in Palk Bay without damage to the ecosystem.

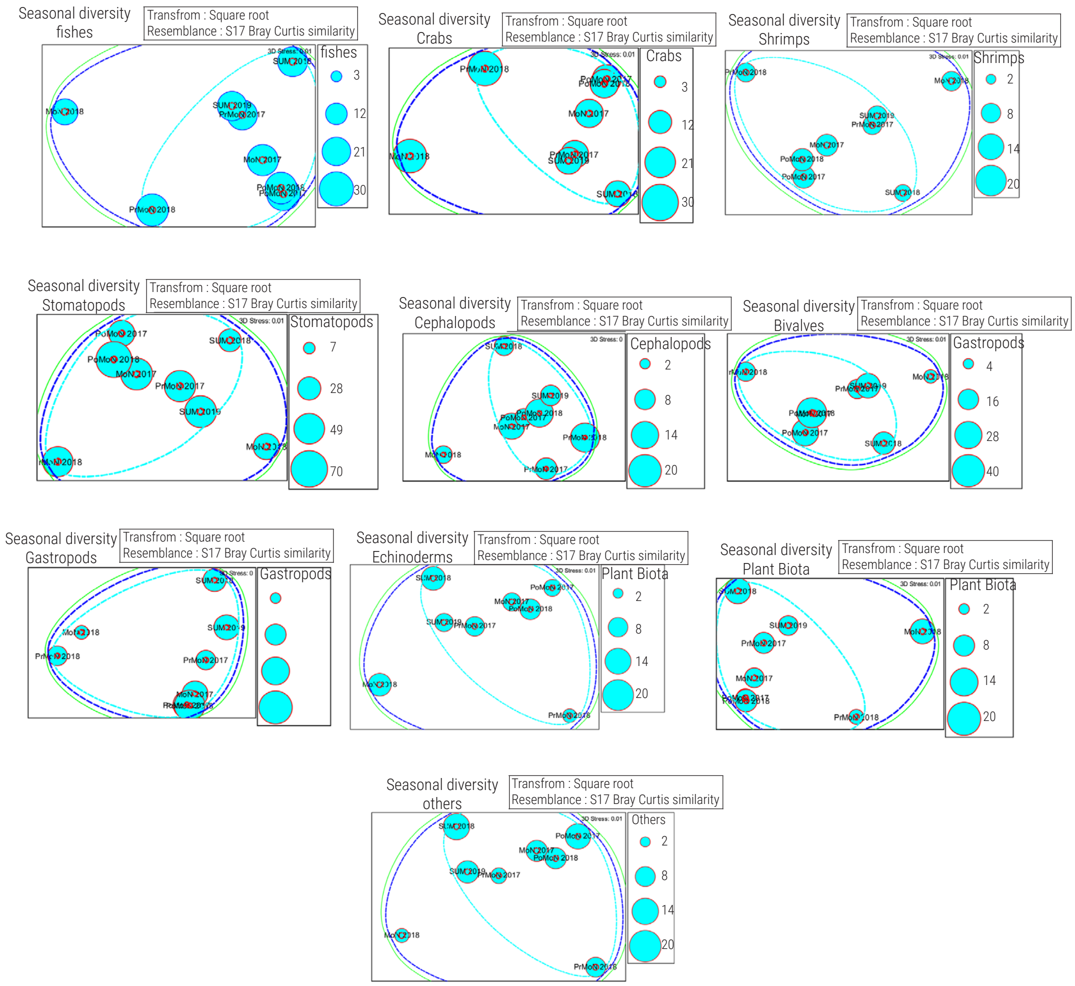

Fig. 11. MDS bubble plot showing the season-wise variation in the biomass of low-value bycatch and overlay of similarity clusters (Bray-Curtis similarity values), set at 10% intervals from 10 to 100% indicated in different colours

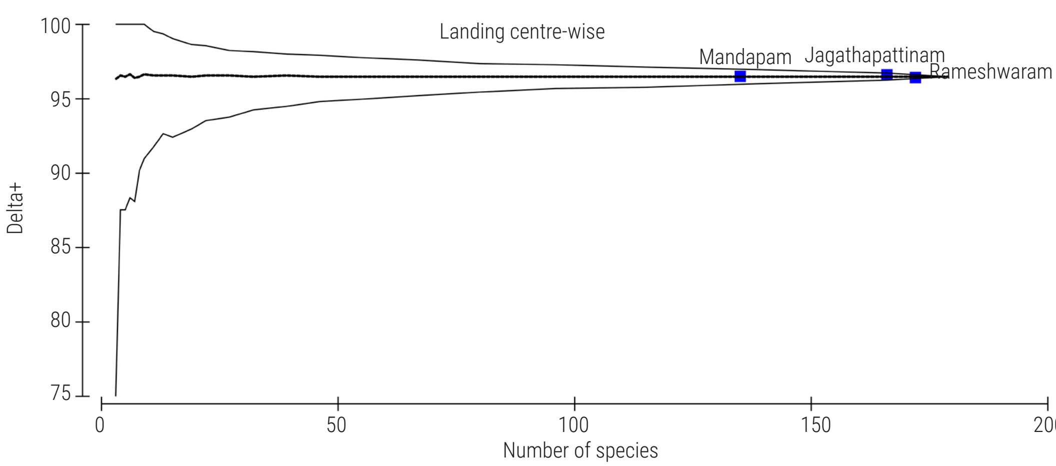

Fig. 12. The 95% confidence funnel for average taxonomic index (Δ+) showing the diversity of low-value fishes in three different landing centres and its deviation from the normal distribution

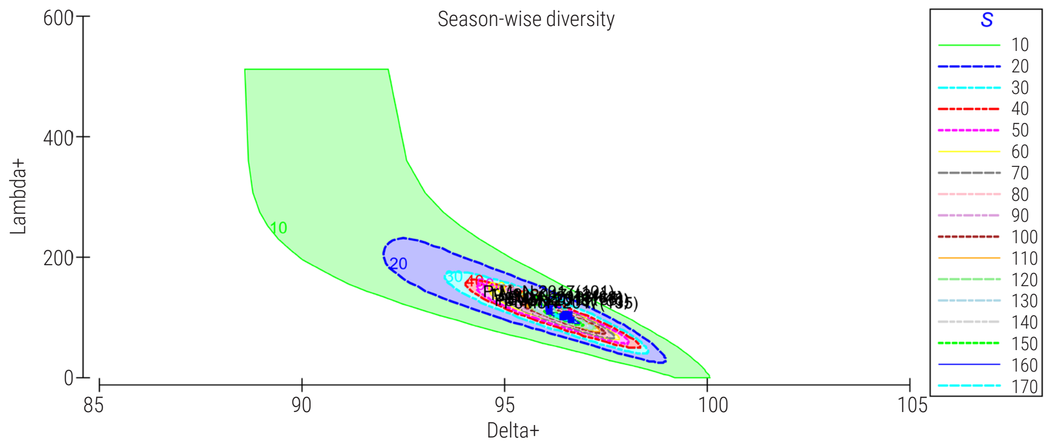

Fig. 13. Fitted 95% probability contours of average taxonomic distinctness (delta+) and variation in taxonomic distinctness (lambda+), showing statistically significant deviation in season-wise fish diversity between the landing centres

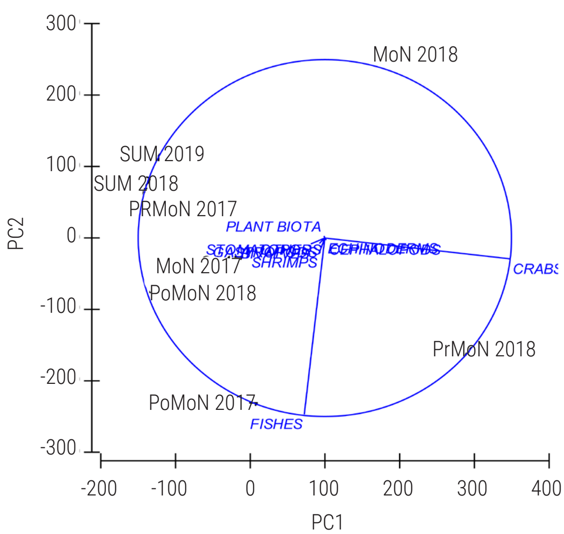

Fig. 14. PCA plot for various groups of season-wise diversity of bycatch

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