Regional Studies in Marine Science 44 (2021) 101755

Contents lists available at ScienceDirect

Regional Studies in Marine Science

journal homepage: www.elsevier.com/locate/rsma

Regional variation in fish species on the continental shelf of Sri Lanka

A. A. Sujeewa Hemanthi Athukoorala[a,b,*], Ram C. Bhujel[a], Jens-Otto Krakstad[c], Takashi Fritz Matsuishi[d]

[a] *Asian Institute of Technology, School of Environment, Resources, and Development, Bangkok, Thailand*
[b] *National Aquatic Resources Research and Development Agency, Colombo, Sri Lanka*
[c] *Institute of Marine Research, Bergen, Norway*
[d] *Hokkaido University, Japan*

ARTICLE INFO

Article history:
Received 30 September 2020
Received in revised form 17 March 2021
Accepted 18 March 2021
Available online 20 March 2021

Keywords:
Sri Lanka
Fish diversity
Fish density
Resource survey

ABSTRACT

Sri Lankan marine fishery resources were not assessed and updated for the last four decades. A comprehensive survey was performed by R.V. Dr. Fridtjof Nansen, starting from June 24 to July 16, 2018. Variations of fish density and diversity on the continental shelf of Sri Lanka were determined by region (East and West) and depth (20–50 m and 50–100 m) using 65 trawl samples collected. Associations between ichthyofauna, ecological parameters, and hydrographic variables (temperature, salinity, and oxygen) were determined. There were 620 species from 137 different families observed during the survey, with family Myctophidae being the most dominant with the highest number of individuals caught from all station (24.61% out of the total number of individuals) while the most represented families by density (t/NM^2) were Carangidae (8.01%). A total of 440 species were found in the East region compared to 385 species in the West region; the density of fish was 1.3 times higher in the East region (9.00 ± 1.08 t/NM^2) compared to the West region (6.85 ± 1.40 t/NM^2). Similarly, the East region was 1.3 higher in the Shannon Wiener's Diversity Index (SWDI) than the West region. Shallow-water (20–50 m) area has been reported as more diverse and denser than deep-water (50–100 m). Canonical correlation analysis showed a positive association of fish density with oxygen and a negative with temperature and salinity. This study would be an invaluable baseline for monitoring future changes and preparing recommendations and management action plans.

1. Introduction

Sri Lanka is an island nation and its coasts have been recognized as biological hotspots in the north Indian Ocean. The location is south-west of the Bay of Bengal and the south-east of the Arabian Sea in the middle of the north Indian Ocean at 5° 55'N - 9° 51'N and 79° 41'E - 81° 53'E (De Vos et al., 2014). The climate and geographical location create a highly variable environment around the island (Sivasubramaniam, 2009). The island is subjected to two monsoons during the periods from May to September; the south-west monsoon (SWM) and from November to April, north-east monsoon (NEM) (Vinayachandran and Yamagata, 1998). The West region is directly faced with SWM and included the north-west, west, and south of the island, while the East region is directly faced with NEM and included the areas of the north-east, east, and south-east part. Sri Lanka has approximately 1620 km coastline and 517,000 km^2 of sea area up to 370 km (200 NM) from the coastline, nearly eight times the country area (Wijayaratne, 2001).

As an island country, fish and fisheries products are primary food sources; per capita, fish consumption is 18 kg per year, slightly lower than the world average of 20.5 kg (FAO, 2020). Fish accounts for 45% of the total animal protein intake and fisheries contribute 1.4% to the Gross Domestic Product (MFAR, 2019). The total marine fisheries production continued rising from 2005, reaching 440,000 MT in 2018 (MFAR, 2019). However, this number is an estimate that probably underestimates the total landings as artisanal catches are poorly documented. More importantly, other Asian countries have also developed aquaculture to increase fish supply, whereas Sri Lanka still depends mainly on the marine catch. Marine resources are depleting in most countries due to overfishing and global warming, and other anthropogenic and natural factors. In the past, the island has suffered from several extreme natural events, e.g., by Tsunami in December 2004 (Poisson et al., 2009), El Nino in 1998, and 2015 which have caused substantial habitat losses of especially shallow-water coral reefs (Zubair et al., 2016).

The health of an ecosystem is expressed in terms of species diversity and density. Moreover, diversity indices of a natural

* Corresponding author at: National Aquatic Resources Research and Development Agency, Colombo, Sri Lanka.
E-mail address: sujeewahemanthi@gmail.com (A.A.S.H. Athukoorala).

https://doi.org/10.1016/j.rsma.2021.101755
2352-4855/

ecosystem may reflect the impact of anthropogenic activities such as fishing and can be used as a monitoring tool (Mcclatchie et al., 1997). The richness in the diversity of an ecosystem indicates a balanced and sound environmental setting. Lack of baseline information withholds changes taking place unknown and may cause overexploitation and extinction of resources. Hence, sound knowledge about the biological system structure is necessary to predict potential changes and formulate an effective resource utilization and conservation policy for marine ecosystems (Fischer and Quist, 2014). Relevant studies are found in Congo (Bianchi, 1992a), Mexico (Bianchi, 1991), the Caribbean Sea (Garcia et al., 1998), Brazil (Nóbrega et al., 2019), Gulf of Mexico (Vega-Cendejas and de Santillana, 2019). They are highlighting the use of such data for sustainable resource utilization around the world. In Sri Lanka, these types of studies have been scarce. The only related study in Sri Lanka was on the reef fish species that focused mainly on the Bar Reef Marine Sanctuary on the north-western coast (Ohman et al., 1997).

Lack of adequate information shows the need for such data to make plans and implement appropriate policies to ensure a sustainable fisheries management system is in place in Sri Lanka. Limited attention is currently given to the biological communities in the ocean. Increasing anthropogenic impacts on resources might have an unseen but significant, detrimental effect on the fisheries' resources and the livelihood of those depending on these resources. In Sri Lanka, impacts on fish population structure are not known, and scientific intervention on fisheries management is scanty. The first scientific stock assessment survey was done in 1978, followed by surveys in 1979 and 1980 by the Dr. Fridtjof Nansen program (DFN) (Blindheim et al., 1979; Blindheim and Foyn, 1980; De Bruin and Saetersdal, 1978). However, those data have been used for stock assessments, while detailed analysis of community structure and diversity have so far not been carried out. Fortunately, after 39 years DFN survey was repeated with financial and technical support from the Food and Agriculture Organization (FAO) and the Norwegian Agency for Development Cooperation (Norad) (Krakstad et al., 2018).

Therefore, this work aimed to examine the fishery resources on the continental shelf of Sri Lanka based on the survey data. Secondly, it was to correlate with the region (East and West), depth (20–50 m and 50–100 m), and environmental parameters (temperature, oxygen, and salinity) and to describe the most significant parameters. The information presented in this paper is the first of its kind that focuses on fish diversity on the continental shelf of Sri Lanka, which should be useful for future monitoring of the resources.

2. Materials and methods

2.1. Survey

The present study is established on trawl data gathered during the survey by the DFN as a part of the Bay of Bengal ecosystem study in 2018 during the south-west monsoon period from June 24 to July 16 on the continental shelf of Sri Lanka (Krakstad et al., 2018). The study area includes the continental shelf not exceeding 100 m bottom depths and covered an area of 4372 NM^2. The survey was designed as a swept area of trawl survey combined with an acoustic assessment of pelagic fish. Bottom trawl samples were taken from pre-defined stratified randomly selected trawl sampling stations (Fig. 1) along pseudo parallel transects perpendicular to the coastline with an inter-transect spacing of 10 NM. There were 82 trawl stations, which included 65 bottom trawls and 17 pelagic trawls. During the survey, when bottom trawling was not possible due to rough or steep bottom conditions or coral reef and sponge habitats, pelagic trawls were occasionally carried out to get better information on biodiversity in the area. Pelagic trawling was also carried out periodically to identify species compositions in pelagic fish schools observed on the echosounder, especially during the nighttime. At each trawl station, hydrographic parameters (temperature, salinity, and oxygen) were also measured.

2.2. Trawl data

The "Super Gisund" bottom trawl attached to the research vessel had a 31 m headline and a 47 m footrope, with an about 5.5 m vertical opening. The cod-end mesh size of the trawl was 20 mm, with a 10 mm inner net attached. During towing, the distance between wingtips was 18.5 m, and a SCANMAR trawl system was used to monitor the performance of the trawl. The towing duration was set at 30 min for every station; the average duration was 27.1 ± 0.52 min, while tawing was done at three knots vessel speed. Due to the very narrow shelf, sampling was done continuously both day and nighttime in a random manner without considering any diel vertical migration of fish at night. The actual swept trawl area was considered as the distance between the wingtips and the haul length measured by the GPS of the SCANMAR® equipment. The "Åkrehamn" pelagic trawl had an eight to 12 m vertical opening during operation.

More details about gears can be found in Krakstad et al. (2018). The pelagic trawl data was not used for quantitative measurements in this analysis. All the samples caught were sorted to the lowest possible taxonomic level. For identification, FAO Species Identification Sheets for Fishery Purposes: Fishing area 51 (Fischer and Bianchi, 1984), FAO Species Identification Guide for Fishery Purposes: The Marine Fishery Resources of Sri Lanka (De Bruin et al., 1994) and online databases FishBase and WoRMS (Froese and Pauly, 2018; WoRMS, 2018) were used. Specimens that could not be identified were retained and identified by experts in taxonomy after the survey. Invertebrates, cartilaginous fishes, jellyfishes, soft corals, sponges, seaweeds, coral species, and garbage were recorded in the trawl catches but excluded from subsequent quantitative analysis in this study. When possible, all specimens of each species in the trawls were counted and weighted. From huge samples, sub-samples were taken. Secondly, the counting and weighing of individuals in the subsamples were converted into the original sample. All national and international guidelines for animal welfare and care were followed during the sampling activities.

2.3. Hydrographic parameters

A Seabird 911 CTD was used to record vertical temperature and salinity profiles, while oxygen was measured by a CTD-mounted SBE 43 oxygen sensors at each bottom trawl station. The oxygen sensor was validated with Winkler titration (Krakstad et al., 2018), while the validation of the salinity sensor was done using a Portasal salinometer from Osil (mod. 8410 A). All parameters were measured at every trawl station to assess the correlation between fish species diversity and density with hydrographic parameters. The average values per parameter per depth category were used for the analysis and the comparisons.

2.4. Data analysis

In this study, actual teleost catches (kg/haul) per each bottom trawl (<100 m depth) per recorded actual trawl distance (NM) was standardized to catch per unit square nautical mile (NM^2) for density calculations. Meanwhile, the ecological parameters, species richness within a particular area (number of species) (Colwell, 2009) and Shannon Wiener's Diversity Index (SWDI)

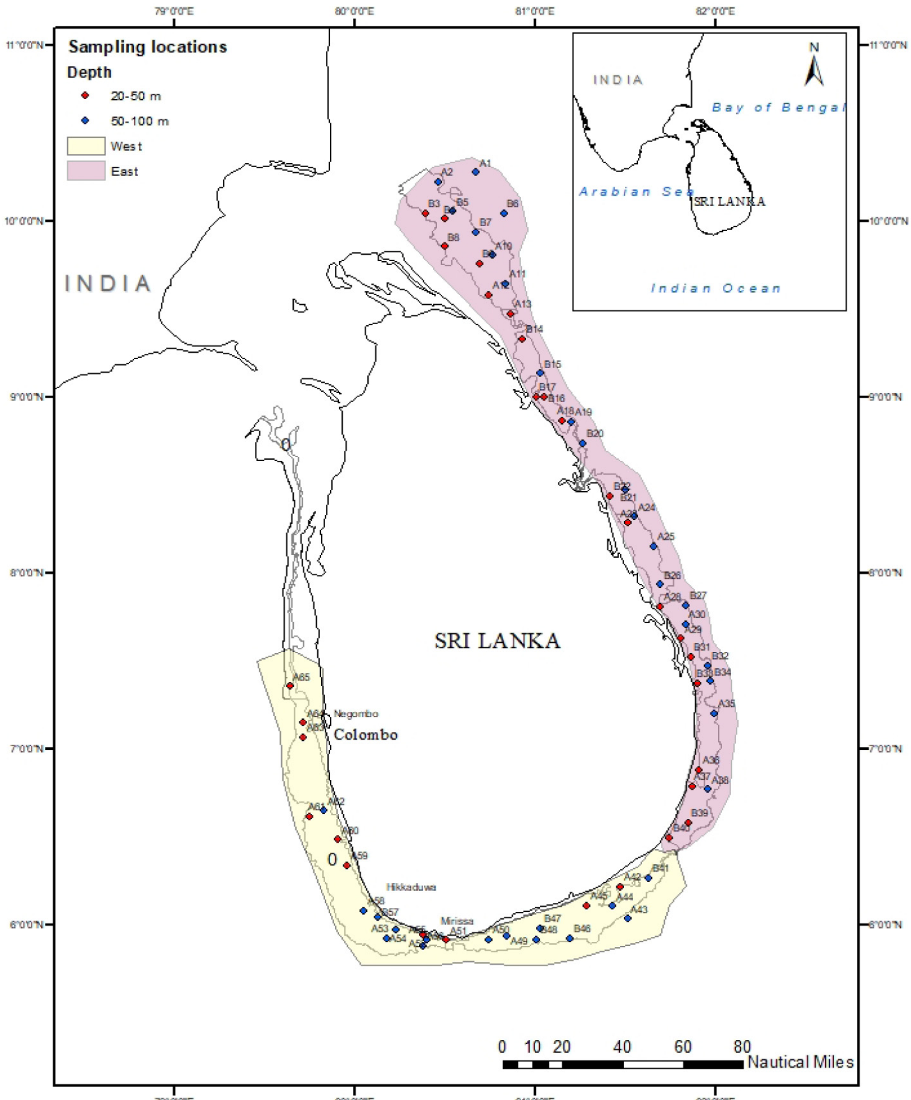

Fig. 1. Trawl stations from the Dr. Fridtjof Nansen survey conducted in 2018 on the continental shelf of Sri Lanka, grouped into region (West and East) and depth (20–50 m), (50–100 m) categories.

$H = -\sum[p_i \ln(p_i)]$, (an index that represents the summary of the diversity of a population) were also calculated with all trawl samples. H is the diversity index, p_i is the relative abundance (n/N), n is the number of individuals for each species, N is the overall number of individuals (Shannon, 1948). The evenness index ($H/H_{\max}$) referred to the community's stability and evaluated the region and depth variance. Where H is the Shannon diversity index, and $H_{\max}$ is the maximum possible value of H in the community (Pielou, 1966). The frequency of occurrence for individual species was calculated as a percentage of a total number of sampled times.

Initially, hierarchical cluster analysis was performed to identify the groups of environments defining a particular region. The output was presented as a dendrogram (Beentjes et al., 2002). The variations of ecological parameters in each region were analyzed with the non-metric multidimensional scaling (NMDS) (Clarke, 1993). NMDS is an analysis ordination widely used in biological data for analyzing patterns in species assemblages; Bray–Curtis dissimilarity measures were also applied to NMDS ordination (Pratchett et al., 2014; Shertzer et al., 2009). Furthermore, this method was chosen because it provides extra weight to plentiful species than to less abundant species and will not be miscalculated by joint absences. The purpose of applying the Bray–Curtis measures to catch rates was to standardize the total to one for every species and do square root transformation. The square root transformation was done to minimize the influence of abundant species and maximize the contribution of species with low abundance (Smith and Lindholm, 2016) to avoid the effects of extreme values. The ecological parameters of species richness, equity, and diversity from each sampling station were obtained and compared to find region characterization.

The patterns in species assemblages between regions; the null hypothesis that the fish species groupings will not significantly vary among regions was done with the two-way permutational analysis of variance (PERMANOVA) (Clarke and Green, 1988). The PERMANOVA relies on Bray–Curtis measures and 999 permutations to remove bias-corrected bootstrap residuals. This analysis method distinguishes the permutation of the distribution statistic described under the null hypothesis that between-group variability is not statistically different from intergroup variability. Bootstrapping was performed to select the most represented unbiased sample based on independent observations (Vega-Cendejas and de Santillana, 2019).

In the next stage of the study, the relationship between environmental parameters and fish assemblages was analyzed by

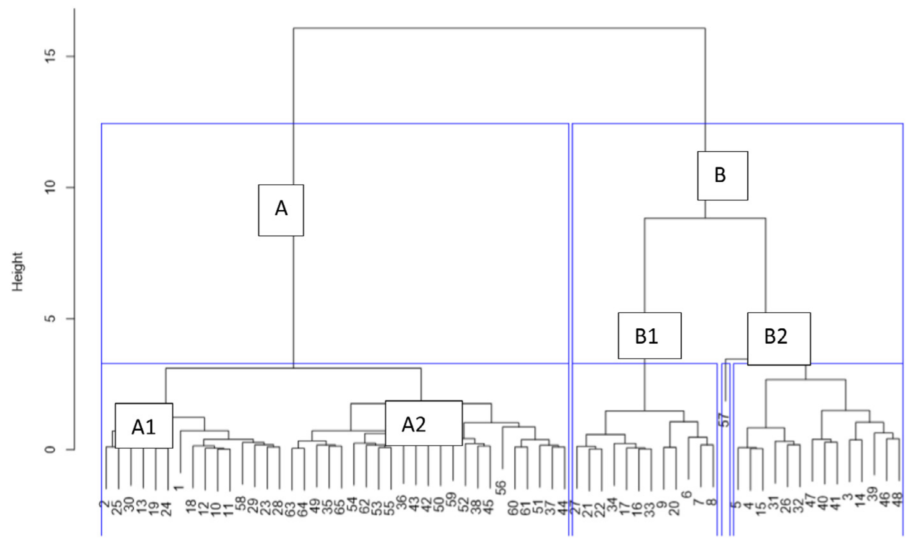

Fig. 2. Cluster dendrogram of the trawling stations based on the hydrographic parameters on the continental shelf of Sri Lanka.

using canonical correlation analysis (Rencher and Christensen, 2012). This method was used to quantify the strength of the relationship between the environmental variable and ecological parameters, which are not directly observed. All analyses used R 4.0.2 (R. core Team, 2020).

3. Results

Cluster analysis of 65 bottom trawl stations shows that there are two major clusters (Fig. 2). The first cluster (A) consists of 38 stations, while the second cluster (B) consisted of 27 stations. Each cluster included two sub-clusters. The East and West regions were separated arbitrarily based on the locations of the sampling sites for this analysis. The East region consisted of locations in the north-east, east, and south-east parts of the country in the Bay of Bengal with the influence of large freshwater seeps. The West region consisted of locations in the west and south parts of the country with influence from the Arabian Sea and strong winds from the SWM. In Cluster A the first Sub-cluster A1 included stations found in the country's north-east and east coast: named as the East region in this analysis. The second Sub-cluster A2 included stations located in the south-west and the west coast of the country named the West region. Similarly, in Cluster B, the first Sub-cluster B1 contained stations located in the east, and the second Sub-cluster B2 contained the stations located in the south and south-east coast that belong to both East and West regions (Fig. 2).

NMDS analysis of the square root transformed density (t/NM^2) for fish species and the ecological parameters indicated a significant difference between the two regions (p <0.001). NMDS plot was slightly overlapping. The final stress value of 0.024 for the two-dimensional solution was found after 20 iterations. The assumption of homogeneity of multivariate dispersion of both regions was rejected (p<0.05) from the PERMANOVA bootstrapping (Table 1).

Table 1
PERMANOVA results comparing the ecological parameters of the samples from each trawl station on the continental shelf of Sri Lanka.

Source of variation	D.F	Sums of sqs.	Mean sqs.	F. model	R^2	p
Region	1	0.155	0.155	11.197	0.033	0.001
Residual	327	4.535	0.014		0.967	
Total	328	4.690			1.000	

(D.F.: a degree of freedom, Sums of sqs: sums of squares, Mean sqs: mean squares).

3.1. Characterization of the trawl catch

There were 620 species from 137 families identified, including a maximum number of teleost and fewer elasmobranchs, cephalopods, crustaceans, decapods, echinoderms, gastropods, and reptiles (Table 2).

The density is over 76% higher (p<0.05) in the East region (9.00 ± 1.08 t/NM^2), compared to the West region (6.85 ± 1.40 t/NM^2) (Table 3), and the mean density was 8.13 ± 0.86 t/NM^2. The East region had the higher value (z= 2.08, p = 0.038) for Shannon Weiner's diversity index (1.81 ± 0.12) and the evenness (0.26 ± 0.02) (z=2.637, p = 0.008). The species richness was 440, belonging to 109 families. Therefore, the East region was more dense, diverse, and heterogeneous than the West region. The species richness in the West region was 385, belonging to 106 families, and the diversity index was 1.44 ± 0.10 (Table 3). The topmost represented families by density in the East region were Carangidae (7.63%), Lethrinidae (5.20%), Lutjanidae (4.91%), Acanthuridae (4.11%), and Caesionidae (3.54%). In the West region, those were Carangidae (7.75%), Lutjanidae (4.16%), Nemipteridae (4.16%), Lethrinidae (3.50%), and Leiognathidae (3.37%).

Among the species, the five most represented families by density (t/NM^2) out of total density were Carangidae (8.01%), Lutjanidae (4.20%), Lethrinidae (4.15%), Acanthuridae (3.62%), and Diodontidae (3.39%). The top five families with the highest species richness recorded were Carangidae (35), Lutjanidae (17), Nemipteridae (17), Acanthuridae (15), and Lethrinidae (15). Twenty-five families accounted for 61.59% of the average total density. Most of them are reef-associated economically important edible fishes. Generally, the majority of the dominant species were most common in shallow-water in both regions. However, the most represented family by the number of individuals caught per station was the family Myctophidae (24.61% out of the total number of individuals). The contribution of dominant families to the density was more similar in both East and West regions. Family Caesionidae is one of the abundant families found in the East region with an average density of 0.4 t/NM^2. The contribution to the total catch from the family Caesionidae is more than double in the East region (3.54%) compared to the West region (1.56%).

Table 2
A list of fish species recorded at more than five stations on the continental shelf of Sri Lanka. Occurrence frequency (O.F), relative density (%D) are classified by regions (East: E, West: W) and depths (20–50 m: I, 50–100 m: II).

Family	Species	O.F.	%D	Region	Depth
ACANTHURIDAE	*Acanthurus mata*	22.09	1.03	E, W	I, II,
	Naso annulatus	11.63	0.65	E, W	I, II
	Naso tuberosus	11.63	0.72	E, W	I, II
AMBASSIDAE	*Ambassis sp.*	27.91	1.12	E, W	I, II,
APOGONIDAE	*Ostorhinchus aureus*	9.30	0.43	W	I, II
BALISTIDAE	*Abalistes stellatus*	34.88	0.89	E, W	I, II
	Balistoides viridescens	9.30	0.43	E, W	I
	Sufflamen sp.	5.81	0.21	W	II,
BOTHIDAE	*Bothus pantherinus*	9.30	0.15	W	I, II
CAESIONIDAE	*Dipterygonotus balteatus*	32.56	1.19	E	I, II
	Pterocaesio chrysozona	9.30	0.80	E, W	I, II
CARANGIDAE	*Alectis ciliaris*	13.95	0.33	E, W	I, II
	Alectis indica	6.98	0.23	E, W	I, II
	Carangoides malabaricus	8.14	0.14	E, W	I, II
	Carangoides sp.	17.44	0.86	E, W	I, II
	Caranx ignobilis	10.47	1.00	E, W	I, II,
	Decapterus macrosoma	27.91	0.51	E, W	I, II,
	Decapterus russelli	25.58	0.45	E, W	I, II,
	Gnathanodon speciosus	8.14	0.31	E, W	I
	Selar crumenophthalmus	22.09	0.63	E, W	I, II,
	Selaroides leptolepis	15.12	0.94	E, W	I, II
CHAETODONTIDAE	*Chaetodon gardineri*	5.81	0.14	W	I, II
	Heniochus acuminatus	8.14	0.57	W	I, II
CLUPEIDAE	*Amblygaster sirm*	8.14	0.27	E, W	I, II
DACTYLOPTERIDAE	*Dactyloptena orientalis*	9.30	0.43	E, W	I, II
DIODONTIDAE	*Cyclichthys orbicularis*	16.28	0.35	E, W	I, II
	Diodon holocanthus	26.74	1.19	E, W	I, II
	Diodon hystrix	17.44	1.23	E, W	I, II
	Diodon sp.	11.63	0.35	E, W	I, II
ENGRAULIDAE	*Stolephorus indicus*	5.81	0.72	E, W	I, II
FISTULARIIDAE	*Fistularia commersonii*	9.30	0.18	E, W	I, II,
	Fistularia petimba	47.67	1.34	E, W	I, II
GEMPYLIDAE	*Promethichthys prometheus*	5.81	0.44	W	I,
GERREIDAE	*Gerres acinaces*	11.63	0.64	E, W	I, II
	Pentaprion longimanus	16.28	0.92	E, W	I,
HAEMULIDAE	*Diagramma pictum*	18.60	0.92	E, W	I, II
	Plectorhinchus ceylonensis	5.81	0.09	E	I, II
HOLOCENTRIDAE	*Sargocentron rubrum*	9.30	0.27	E, W	II,
LEIOGNATHIDAE	*Equulites elongatus*	27.91	1.09	E, W	I, II
	Leiognathus berbis	5.81	0.20	E, W	I, II
	Photopectoralis bindus	5.81	0.20	E, W	I, II
LETHRINIDAE	*Gymnocranius elongatus*	5.81	0.08	E	I, II
	Gymnocranius griseus	5.81	0.18	E, W	I, II
	Lethrinus lentjan	11.63	0.90	E, W	I, II
	Lethrinus nebulosus	19.77	1.11	E, W	I, II
	Lethrinus olivaceus	19.77	0.87	E, W	I, II
LUTJANIDAE	*Lutjanus argentimaculatus*	13.95	0.55	E, W	I, II
	Lutjanus erythropterus	11.63	0.26	E, W	I, II
	Lutjanus lutjanus	5.81	0.38	E, W	I, II
	Lutjanus quinquelineatus	13.95	0.49	E	I, II
	Lutjanus rivulatus	20.93	1.30	E, W	I, II
	Lutjanus vitta	8.14	0.43	E, W	I, II
MONACANTHIDAE	*Aluterus monoceros*	5.81	0.44	E, W	I, II
	Aluterus scriptus	12.79	0.20	E, W	I
	Aluterus sp.	5.81	0.09	E, W	I
	Paramonacanthus nipponensis	19.77	0.25	W	I, II,
MULLIDAE	*Parupeneus forsskali*	8.14	0.15	E, W	I, II
	Parupeneus indicus	16.28	0.28	E, W	I, II
	Upeneus bensasi	6.98	0.09	E, W	I, II
	Upeneus moluccensis	5.81	0.39	E, W	I, II
MURAENESOCIDAE	*Congresox talabon*	5.81	0.24	E, W	II,
MYCTOPHIDAE	*Gonichthys sp.*	5.81	0.23	W	I, II,
NEMIPTERIDAE	*Nemipterus bipunctatus*	26.74	0.64	E, W	I, II
	Nemipterus furcosus	16.28	0.33	E, W	I, II
	Nemipterus japonicus	5.81	0.14	E, W	I, II
	Nemipterus randalli	9.30	0.11	E, W	II
	Nemipterus zysron	12.79	0.74	E, W	I, II
	Scolopsis bimaculata	27.91	0.76	E, W	I, II
OSTRACIIDAE	*Lactoria cornuta*	11.63	0.89	E, W	I, II
	Ostracion cubicus	6.98	0.30	E, W	I
	Ostracion sp.	5.81	0.15	E, W	I, II
	Tetrosomus gibbosus	33.72	1.08	E, W	I, II

(*continued on next page*)

Table 2 (*continued*).

Family	Species	O.F.	%D	Region	Depth
PARALICHTHYDAE	*Pseudorhombus elevatus*	10.47	0.69	E	I, II
PEMPHERIDAE	*Pempheris sp.*	5.81	0.08	E, W	I, II
PLATYCEPHALIDAE	*Rogadius pristiger*	5.81	0.06	W	II
PLOTOSIDAE	*Plotosus lineatus*	6.98	0.16	E, W	I, II
POMACENTRIDAE	*Chromis sp.*	8.14	0.15	E, W	I, II
PRIACANTHIDAE	*Cookeolus japonicus*	8.14	0.16	E, W	I, II,
	Cookeolus sp.	8.14	0.43	E, W	I, II
	Priacanthus hamrur	26.74	0.59	E, W	I, II,
PSETTODIDAE	*Psettodes erumei*	5.81	0.07	S, W	I, II
SCARIDAE	*Scarus rubroviolaceus*	5.81	0.33	E, W	I, II
SCOMBRIDAE	*Auxis thazard*	5.81	0.53	W	I, II,
SCORPAENIDAE	*Pterois antennata*	5.81	0.11	E, W	I, II
	Pterois sp.	5.81	0.14	E, W	I, II
SERRANIDAE	*Epinephelus coioides*	8.14	0.21	E, W	I, II
	Epinephelus malabaricus	6.98	0.58	E, W	I, II
	Epinephelus undulosus	16.28	0.46	E, W	I, II
SPHYRAENIDAE	*Sphyraena forsteri*	18.60	0.52	E, W	I, II
	Sphyraena jello	13.95	0.37	E, W	I, II,
	Sphyraena obtusata	11.63	0.79	E, W	I, II
SYNODONTIDAE	*Saurida nebulosa*	12.79	0.34	E, W	I, II
	Saurida tumbil	15.12	0.29	E, W	I, II
	Synodus dermatogenys	12.79	0.27	E, W	I, II
	Synodus indicus	10.47	0.75	E, W	I, II
	Trachinocephalus myops	16.28	0.20	E, W	I, II
TETRAODONTIDAE	*Arothron hispidus*	8.14	0.14	E, W	I, II
	Arothron immaculatus	5.81	0.21	E, W	I
	Arothron stellatus	6.98	0.16	E, W	I, II
	Chelonodon sp.	5.81	0.18	E	I, II
	Lagocephalus lunaris	8.14	0.13	E, W	I, II

Table 3
The ecological parameters of the fish communities on the continental shelf of Sri Lanka classified by regions (East and West) and depth (20–50 m and 50–100 m) calculated from the trawl data collected from June 24 to July 16, 2018.

Categories	Region		Depth	
Ecological parameter	East	West	20–50 m	50–100 m
No. of Families	109	106	95	86
Species richness	440	385	409	327
SWDI	1.81 ± 0.12^{a}	1.44 ± 0.10^{b}	1.72 ± 0.13^{a}	1.67 ± 0.12^{b}
Evenness	0.26 ± 0.02^{a}	0.18 ± 0.02^{b}	0.52 ± 0.04^{b}	0.54 ± 0.04^{a}
Density (t/NM^2)	9.00 ± 1.08^{a}	6.85 ± 1.40^{b}	13.18 ± 2.06^{a}	10.18 ± 2.18^{b}

Note: SWDI means Shannon Wiener's Diversity Index. Values between regions across all depths and between depths across all regions with different superscripts are significantly different at a 5% level of significance.

Meanwhile, analyzed with the depth categories, the family Carangidae remained as the most abundant family in the shallow-water area (20–50 m). This depth category was having elevated species richness (409 species) and SWDI value (1.72 ± 0.13). However, in the deep-water category (50–100 m), the species richness and diversity were relatively poor (Table 3). The comparison of depth category data confirmed that the significant difference in species diversity and density. In shallow-water, fish density, species richness, SWDI were higher than in deep-waters. The shallow-water layer, the top five dominant fish families from the total density were Carangidae (10.00%), Lethrinidae (5.94%), Leiognathidae (4.87%), Diodontidae (4.47%), Caesionidae (4.12%). The fish community in deep-waters were represented by lesser species richness (327), but evenness was high, signifying that species are more heterogeneous than shallow-water. In the deep layer, the most represented five families by total catch were Lutjanidae (9.27%), Acanthuridae (7.52%), Carangidae (5.21%), Serranidae (4.36%), Nemipteridae (3.89%). The species present in both region and depth categories were listed in Table 2.

3.2. Hydrographic parameters

The average water temperature for the survey area was 26.03± 0.37 °C having a significant difference among the two regions (p<0.05). The East region (27.05 ± 0.57 °C) had approximately 2 °C higher than in the West region (25.01 ± 0.51 °C). Dissolved oxygen concentration averaged 1.68 ± 0.07 ml/l, with a higher value (p<0.05) also in the East region (1.95 ± 0.12 ml/l). The mean salinity was 34.34 ± 0.05 ppt, with a higher value in the West region (34.76 ± 0.03 ppt) (Table 4). Differences in each parameter between regions are evidence of the influence of monsoonal changes.

Table 4
Average values of hydrographic parameters (oxygen, salinity, and temperature) on the continental shelf of Sri Lanka by East and West regions during the Dr. Fridtjof Nansen survey June 24 to July 16, 2018.

Parameter	Mean value	Region	
		East	West
Temperature (°C)	26.03 ± 0.37	27.05 ± 0.57^{x}	25.01 ± 0.51^{y}
Oxygen (ml/l)	1.68 ± 0.07	1.95 ± 0.12^{x}	1.41 ± 0.09^{y}
Salinity (ppt)	34.34 ± 0.05	34.17 ± 0.08^{x}	34.76 ± 0.03^{y}

Different superscripts are significantly different at 5% level of significance.

Canonical correlation analysis (CCA) with environmental parameters and ecological parameters explained 60.1% variation (Fig. 3). The first two axes explain 58.0% of the variation. The environmental parameters: oxygen, temperature, and salinity explained the changes in fish diversity and density. There are 23.4% of the variations explained by axis 1, with a positive correlation of oxygen and negative correlation of temperature and salinity at sampling stations in East and West regions. Oxygen had a strong influence at stations in deep water.

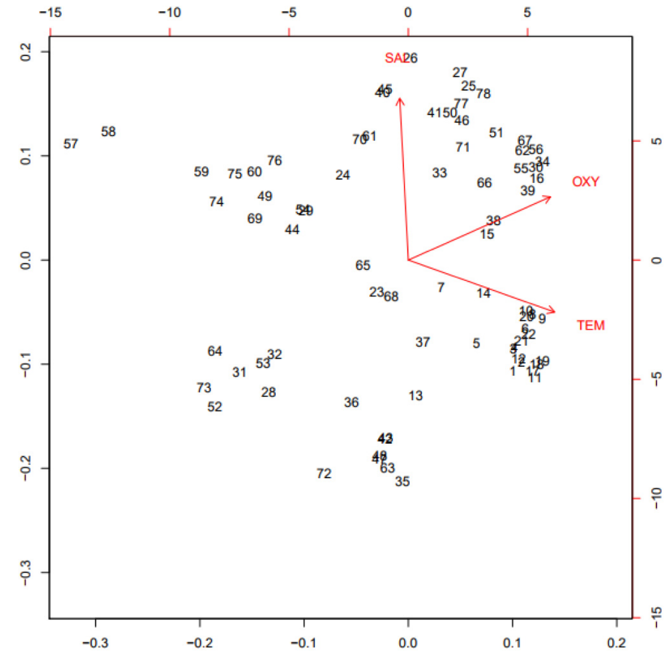

Fig. 3. Ordination biplot of CCA based on species density, with environmental parameters: Temperature = TEM, salinity = SAL, dissolved oxygen=OXY. Arrow direction and the length specify the comparative significance and force of change in the environmental parameters. Numbers represent the sampling points in each cluster.

4. Discussion

The continental shelf of Sri Lanka has a rich ecosystem because of its oceanographic, hydrographic, climatic, and geological diversity (Balasuriya, 2018). These factors give an enormous mixture of ecosystems and guide to a vigorous marine fauna association. The east and west sides of the country have different environmental conditions and face two different monsoons. Monsoonal impacts are among the most significant factors affecting Sri Lanka's marine biodiversity (De Bruin et al., 1994). In addition to these, other reasons are the differences in shape and steepness of the narrow continental shelf. The south coast of Sri Lanka is recorded as one of the world's steepest continental shelves (De Vos et al., 2014). Labropoulou and Papaconstantinou (2000) have documented the influence of the depth and changes of the continental slope on different environmental parameters and the different fish species diversities and densities. The SWM is prominent in the country with strong currents and heavy rains than the NEM with weaker currents and less rains (Shankar et al., 2002). During the SWM, highly saline warm water from the Arabian Sea is transported from west to east. Coastal upwellings occur at the west and south coasts in this period, and reported chlorophyll concentration had been observed to be as high as > 5 mg/m^{-3} (De Vos et al., 2014; Vinayachandran, 2004). This causes high biological productivity over the SWM period, particularly on the south coast. If the productivity is high, it causes substantial heterogeneity and higher fisheries production in the coastal ecosystem (Petrik et al., 2019).

In contrast, our findings point out less diversity and lower density values in the West region than in the East region. Colombo, the Sri Lanka capital, is situated in the West region, surrounded by several other large cities. West region is well-known among tourists, specially Unawatuna, Hikkaduwa, Mirissa, Negombo, etc. Relatively more significant anthropogenic influences, including; sand mining, coral mining, destructive fishing methods, habitat destruction, dredging, and coastal development activities, are taking place in the West region (Balasuriya, 2018; Senevirathna et al., 2018). The frequency of accumulation of microplastic pollutants is also higher in this region (Jang et al., 2018; Koongolla et al., 2018; Ranatunga and Karunaratna, 2018). Senevirathna et al. (2018) pointed out that the sediments from the coastal erosion resulting from coastal development activities can deposit on the coral reefs and create a deadly situation for the coral-associated fauna.

The East region has about 4000 ha of mangroves, more than 60,000 ha lagoons, and over 9000 ha salt marshes (MFAR, 2019). The West region's total mangrove area was nearly 1000 ha, lagoons about 9000 ha, and salt marshes 1000 ha (MFAR, 2019). The habitat of East region is significantly different as it has four times more mangroves, six times lagoons, and nine times salt marshes than the West region. Mangroves, lagoons, and salt marshes are nursery and breeding sites for many reef-associated fish species (Balasuriya, 2018). Moreover, human population density is nearly five times higher in the West region than in the East region (DCS, 2012). Human impacts including, fishing, habitat destruction, and destructive fishing practices, are the major factors that negatively affect marine resources. For example, the West region's total marine fisheries production was about four times higher than that of East region in 2018 (MFAR, 2019). Marine pollution level is assumed to be higher in the West region because of urbanization. The East region suffered a 30-year civil war that restricted fishing activities and civilization (MOD, 2011). Fishing activities and civilization have started after the ceasefire in 2009. Thus, rich habitats, less fishing mortality, and low anthropogenic activities might be the reasons for higher fish density and greater biodiversity in the East region.

The continental shelf of Sri Lanka is narrow, not extending beyond 15 NM from the coast except in the north region. The offshore extension of the shelf ends with a very steep slope around 100 m depth, where the bottom generally falls off to greater than 2000 m depth (Katupotha, 2016). The north region's Bathymetry charts show Sri Lankan and Indian continents are conjoins, and the shelf is shallow and broader (Rao et al., 2011). The shallow areas less than 20 m depth were not surveyed due to safety depth limitations set by the DFN. The deeper areas greater than 100 m were also mainly untrawlable due to the slope's steepness. Therefore, bottom trawling had been restricted only to the depth between 20–100 m and on locations where this could be done without habitat destruction. As a result, the sampling size is not equally distributed. Due to unequal sampling size, the effect on the significance levels of ANOVA tests and the Type 1 error rates can increase dramatically (Rusticus and Lovato, 2014).

The most represented family in respect of the number of individuals was a deep-sea lantern fish belonging to the family Myctophidae. There is no commercial fisheries interest in this resource other than as bycatch and ended as waste. Low fishing mortality probably explains the higher abundance. The most represented family by weight was the Carangidae (trevally), followed by Lutjanidae (snappers) and Lethrinidae (breams). Most of the species in these families are rocks and coral reef-associated commercially important food fish in high demand. These species are therefore more tentative to be overexploited in the absence of proper monitoring and control measures. These species were not unexpectedly more common in the East region, where there is less fishing activity.

An important conclusion from this work was that 64% of abundant ichthyofauna's optimum depth was in shallow-water (20–50 m). It is generally accepted that depth is the primary variable that affects the sea's faunal changes (Bianchi, 1992b,a, 1991; Labropoulou and Papaconstantinou, 2004). Two depth categories were defined in the survey as the continental shelf position: 20–50 m depth (inner shelf) and 50–100 m depth (outer shelf). A study was done by Gray and Otway (1994) also reported the significant change in density and diversity with different depth levels in the inner continental shelf off Sydney, Australia, with higher values at shallow depths. Many studies have explained the higher primary production in the shallow coastal waters around Sri Lanka (De Vos et al., 2014; Shankar et al., 2002; Unnikrishnan and Shankar, 2007; Vinayachandran, 2004). Species diversity has shown a decreasing trend with the increasing bottom depth. Similar results were recorded by the Beentjes et al. (2002), a study conducted at New Zealand islands. Surface layers are subjected to year-round even sunlight due to tropical climate and optimum mixing by heavy currents brought from strong monsoon winds (Shankar et al., 2002). Therefore, optimum conditions, including food availability and dissolved oxygen, might be the reason for the increased density recorded in the shallow-water.

The present study provides a number of baseline data for fish fauna around the continental shelf of Sri Lanka. Hydrographic parameters are considered one of the significant factors affecting the faunal diversity and density in the marine ecosystem, in addition to direct and indirect human impacts (Vega-Cendejas and de Santillana, 2019). A study performed by Bianchi (1991) reported a strong correlation in the different assemblages of fish with temperature and oxygen. This study also found the same results by reporting higher fish density in the East region with higher dissolved oxygen concentration. The CCA results showed a negative correlation in salinity and temperature on fish abundance, proving the less density in the West region with higher salinity. Shannon Weiner's diversity index and evenness values were comparatively higher in the East region. Therefore, the East region of Sri Lanka is more diverse and heterogeneous than the West region. Significantly different diversity indexes of two regions are providing evidence for two distinct environments in the East and the West regions. We believe that the sum of all anthropogenic impact combined with the environmental impacts are the reasons for these observed differences in density and diversity in the East and West regions.

Understanding fish communities and interrelationship with the ecosystem is considered one of the most important steps in modern fisheries management (Beentjes et al., 2002). It is generally accepted that long-term changes in hydrographic parameters significantly impact the fish population dynamics. As well as industrial fishing is also a key source of faunal dynamics over time. A growing body of evidence showed decreased abundance from overfishing (Fisher and Frank, 2004). Therefore, understanding the fish communities and how commercial fishery impacts both the regions is vital for sustainable fisheries management. Our study also found that temperature is critical in changing ichthyofaunal density.

Consequently, immediate environmental extremes (El Nino) and long-term climatic changes (global warming) are more tentatively to determine population dynamics and should be monitored closely. The present results are still insufficient to conclude about marine biodiversity in Sri Lanka. It is recommended to develop and maintain an authoritative list of marine species off Sri Lanka to understand biodiversity better.

5. Conclusions

A total of 620 fish species from 137 different families were found in the coastal regions of Sri Lanka. The Myctophidae was the dominant family with nearly 25% based on the number of individuals out of the total number of individuals in the survey. A total of 440 species were found in the East region and 385 species in the West region. The fish density was higher (9.00 ± 1.08 t/NM^2) in the East region compared to the West region (6.85 ± 1.40 t/NM^2). Similarly, the East region showed a 26% higher Shannon Wiener's Diversity Index (SWDI) than the West region. Water temperature and dissolved oxygen were significantly higher in the East region. Whereas salinity was higher in the West region. Shallow-water (20–50 m) was more diverse and denser than deep-water (50–100 m). Therefore, the shallow-water area in the East region is significantly different in fish diversity and the density on the continental shelf of Sri Lanka. Continuous monitoring, conservation, and implementation of best management practices are recommended to protect marine resources on the continental shelf of Sri Lanka. Knowledge gained from this study about fish species diversity and density should be utilized in management and decision-making for the sustainable utilization of resources. Further research should be initiated with the present results for the protection of habitat and species diversity.

CRediT authorship contribution statement

A. A. Sujeewa Hemanthi Athukoorala: Methodology, Formal analysis, Writing - original draft. **Ram C. Bhujel:** Supervision. **Jens-Otto Krakstad:** Writing - review & editing. **Takashi Fritz Matsuishi:** Conceptualization, Visualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The study was funded by Sri Lanka Council for the Agricultural Research Policy (SLCARP). This paper uses data collected through the scientific survey with the research vessel Dr. Fridtjof Nansen off Sri Lanka in 2018 as part of the collaboration between FAO on behalf of the EAF-Nansen Program and Sri Lanka. The EAF-Nansen Program is a partnership between the Food and Agriculture Organization of the United Nations (FAO), the Norwegian Agency for Development Cooperation (Norad), and the Institute of Marine Research (IMR) in Norway for sustainable management of the fisheries resources in partner countries. The authors thank all the persons from the National Aquatic Resources Research and Development Agency (NARA) and IMR who contributed to the survey, laboratory analysis, and other activities. Special thanks are due to Jagath Rajapaksha and Rajitha Athukorala for help in map preparation. Thanks for allowing us to use the survey data to analyze and prepare this paper in partial fulfillment of the requirements for the Ph.D. studies of the first Author at the Asian Institute of Technology located near Bangkok.

References

Balasuriya, A., 2018. Coastal area management: Biodiversity and ecological sustainability in Sri Lankan perspective. In: Biodiversity and Climate Change Adaptation in Tropical Islands. Elsevier Inc., pp. 701–724. http://dx.doi.org/10.1016/B978-0-12-813064-3.00025-9.

Beentjes, M.P., Bull, B., Hurst, R.J., Bagley, N.W., 2002. Demersal fish assemblages along the continental shelf and upper slope of the east coast of the South Island, New Zealand. New Zeal. J. Mar. Freshw. Res. 36, 197–223. http://dx.doi.org/10.1080/00288330.2002.9517080.

Bianchi, G., 1991. Demersal assemblages of the continental shelf and slope edge between the Gulf of Tehuantepec (Mexico) and the Gulf of Papagayo (Costa Rica). Mar. Ecol. Prog. Ser. 73, 121–140. http://dx.doi.org/10.3354/meps073121.

Bianchi, G., 1992a. Study of the demersal assemblages of the continental shelf and upper slope off Congo and Gabon, based on the trawl surveys of the RV "Dr Fridtjof Nansen". Mar. Ecol. Prog. Ser. 85, 9–23. http://dx.doi.org/10.3354/meps085009.

Bianchi, G., 1992b. Demersal assemblages of the continental shelf and upper slope of Angola. Mar. Ecol. Prog. Ser. 81, 101–120. http://dx.doi.org/10.3354/meps081101.

Blindheim, J., de Bruin, G.H.P., Saetersdal, G., 1979. A Survey of the Coastal Fish Resources of Sri Lanka. Bergen/ColomboFisheries Research Station, Institute of Marine Research.

Blindheim, J., Foyn, L., 1980. A survey of the coastal fish resources of Sri Lanka, report no.III, http://dx.doi.org/10.1017/CBO9781107415324.004.
Clarke, K.L., 1993. Non-parametric multivariate analyses of change in community structure. Aust. J. Ecol. 18, 117–143.
Clarke, K.l., Green, R.H., 1988. Statistical design and analysis for a 'biological effects' study. Ecol. Prog. Ser. 46, 213–226.
Colwell, R.K., 2009. Biodiversity: Concepts, patterns and measurement. In: Levin, S.A. (Ed.), The Princeton Guide to Ecology. Princeton University Press, Princeton, pp. 257–263.
DCS, 2012. Census of population and housing 2012- final report [www document]. Dep. Census Stat. URL http://www.statistics.gov.lk/Population/StaticalInformation/VitalStatistics.
De Bruin, G.H.P., Russell, B.C., Bogusch, A., 1994. FAO species identification field guide for fishery purposes. In: The Marine Fishery Resources of Sri Lanka. Rome, Italy.
De Bruin, G.H.P., Saetersdal, G.S., 1978. A survey of the coastal fish resources of Sri Lanka - august - september 1978.
De Vos, A., Pattiaratchi, C.B., Wijeratne, E.M.S., 2014. Surface circulation and upwelling patterns around Sri Lanka. Biogeosciences 11, 5909–5930. http://dx.doi.org/10.5194/bg-11-5909-2014.
FAO, 2020. The State of World Fisheries and Aquaculture 2020 Sustainability in action. Rome.
Fischer, W., Bianchi, G., 1984. FAO Species Identification Sheets for Fishery Purposes: Western Indian Ocean (Fishing Area 51). Food and Agricultural Organization of the United Nations, Rome.
Fischer, J., Quist, M.C., 2014. Gear and seasonal bias associated with abundance and size structure estimates for lentic freshwater fishes. J. Fish Wildl. Manage. 5, 394–412. http://dx.doi.org/10.3996/082013-JFWM-054.
Fisher, J.A.D., Frank, K.T., 2004. Abundance-distribution relationships and conservation of exploited marine fishes. Mar. Ecol. Prog. Ser. 279, 201–213. http://dx.doi.org/10.3354/meps279201.
Froese, R., Pauly, D., 2018. FishBase [WWW Document]. URL www.fishbase.org.
Garcia, C.B., Duarte, L.O., von Schiller, D., 1998. Demersal fish assemblages of the Gulf of Salamanca, Colombia (southern Caribbean Sea). Mar. Ecol. Prog. Ser. 174, 13–25.
Gray, C.A., Otway, N.M., 1994. Spatial and temporal differences in assemblages of demersal fishes on the inner continental shelf off sydney, south-eastern australia. Mar. Freshw. Res. 45, 665–676. http://dx.doi.org/10.1071/MF9940665.
Jang, Y.C., Ranatunga, R.R.M.K.P., Mok, J.Y., Kim, K.S., Hong, S.Y., Choi, Y.R., Gunasekara, A.J.M., 2018. Composition and abundance of marine debris stranded on the beaches of Sri Lanka: Results from the first island-wide survey. Mar. Pollut. Bull. 128, 126–131. http://dx.doi.org/10.1016/j.marpolbul.2018.01.018.
Katupotha, J., 2016. Future prospects of quaternary climatic studies of Sri Lanka; a Review. 4, pp. 190–208.
Koongolla, J.B., Andrady, A.L., Kumara, P.B.T.P., Gangabadage, C.S., 2018. Evidence of microplastics pollution in coastal beaches and waters in southern Sri Lanka. Mar. Pollut. Bull. 137, 277–284. http://dx.doi.org/10.1016/j.marpolbul.2018.10.031.
Krakstad, J.-O., Jayasinghe, P., Totland, A., Dalpadado, P., Søiland, H., Cervantes, D., Gunasekara, S., Liyanage, U., Haputhantri, S., Rathnasuriya, I., Wimalasiri, U., Weerakoon, A., Nirbadha, S., Harischandra, A., Wanigatunga, R., Kithsiri, P., 2018. Survey of Regional Resources and Ecosystem of the Bay of Bengal, 24 June-16 July 2018. EAF-Nansen/CR/2018/8.
Labropoulou, M., Papaconstantinou, C., 2000. Community structure of deep-sea demersal fish in the North Aegean Sea (northeastern Mediterranean). Hydrobiologia 440, 281–296. http://dx.doi.org/10.1023/A:1004199917299.
Labropoulou, M., Papaconstantinou, C., 2004. Community structure and diversity of demersal fish assemblages: the role of fishery. Sci. Mar. 68, 215–226. http://dx.doi.org/10.3989/scimar.2004.68s1215.
Mcclatchie, S., Millar, R.B., Webster, F., Lester, P.J., Hurst, R., Bagley, N., 1997. Demersal fish community diversity off New Zealand: Is it related to depth, latitude and regional surface phytoplankton? Deep. Res. 44, 647–667.
MFAR, 2019. Fisheries Statistics. Ministry of Fisheries and Aquatic Resources, Sri Lanka.
MOD, 2011. Humanitarian Operation Factual Analysis July 2006-May 2009. Ministry of Defence Democratic Socialist Republic of Sri Lanka, Colombo.
Nóbrega, M.F., Garcia, J.J., Rufener, M.C., Oliveira, J.E.L., 2019. Demersal fishes of the northeast Brazilian continental shelf: Spatial patterns and their temporal variation. Reg. Stud. Mar. Sci. 27, 100534. http://dx.doi.org/10.1016/j.rsma.2019.100534.
Ohman, M.C., Rajasuriya, A., Olafsson, E., 1997. Reef fish assemblages in north-western Sri Lanka: Distribution patterns and influences of fishing practises. Environ. Biol. Fishes. 49, 45–61. http://dx.doi.org/10.1023/A:1007309230416.
Petrik, C.M., Stock, C.A., Andersen, K.H., van Denderen, P.D., Watson, J.R., 2019. Bottom-up drivers of global patterns of demersal, forage, and pelagic fishes. Prog. Oceanogr. 176, 102124. http://dx.doi.org/10.1016/j.pocean.2019.102124.
Pielou, E.C., 1966. The measurement of diversity in different types of biological collections. J. Theoret. Biol. 13, 131–144. http://dx.doi.org/10.1016/0022-5193(66)90013-0.
Poisson, B., Garcin, M., Pedreros, R., 2009. The 2004 december 26 Indian ocean tsunami impact on Sri Lanka: Cascade modelling from ocean to city scales. Geophys. J. Int. 177, 1080–1090. http://dx.doi.org/10.1111/j.1365-246X.2009.04106.x.
Pratchett, M.S., Hoey, A.S., Cvitanovic, C., Hobbs, J.P.A., Fulton, C.J., 2014. Abundance, diversity, and feeding behavior of coral reef butterflyfishes at Lord Howe Island. Ecol. Evol. 4, 3612–3625. http://dx.doi.org/10.1002/ece3.1208.
R. core Team, 2020. A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.
Ranatunga, R.R.M.K.P., Karunaratna, K.P.R., 2018. First evidence of microplastics in beach sand from negombo, Sri Lanka and the potential accumulation in marine fish. Int. Conf. Multidiscip. Approaches.
Rao, R.R., Girishkumar, M.S., Ravichandran, M., Gopalakrishna, V.V., Thadathil, P., 2011. Do cold, low salinity waters pass through the Indo-Sri Lanka channel during winter? Int. J. Remote Sens. 32, 7383–7398. http://dx.doi.org/10.1080/01431161.2010.523728.
Rencher, A.C., Christensen, W.F., 2012. Methods of Multivariate Analysis New Jersey. John Wiley & Sons.
Rusticus, S., Lovato, C., 2014. Impact of sample size and variability on the power and type i error rates of equivalence tests: A simulation study. Pract. Assess. Res. Eval. 19.
Senevirathna, E.M.T.K., Edirisooriya, K.V.D., Uluwaduge, S.P., Wijerathna, K.B.C.A., 2018. Analysis of causes and effects of coastal erosion and environmental degradation in southern coastal belt of Sri Lanka special reference to unawatuna coastal area. Procedia Eng. 212, 1010–1017. http://dx.doi.org/10.1016/j.proeng.2018.01.130.
Shankar, D., Vinayachandran, P.N., Unnikrishnan, A.S., 2002. The monsoon currents in the north Indian Ocean. Prog. Oceanogr. 52, 63–120.
Shannon, C.E., 1948. A mathematical theory of communication. Bell. Syst. Tech. J. 27, 379–423, 623–656.
Shertzer, K.W., Williams, E.H., Taylor, J.C., 2009. Spatial structure and temporal patterns in a large marine ecosystem: Exploited reef fishes of the southeast United States. Fish. Res. 100, 126–133. http://dx.doi.org/10.1016/j.fishres.2009.06.017.
Sivasubramaniam, K., 2009. Fisheries in Sri Lanka, Vol. 1. Kumaran Book House, Colombo.
Smith, J.G., Lindholm, J., 2016. Vertical stratification in the distribution of demersal fishes along the walls of the La Jolla and Scripps submarine canyons, California, USA. Cont. Shelf Res. 125, 61–70. http://dx.doi.org/10.1016/j.csr.2016.07.001.
Unnikrishnan, A.S., Shankar, D., 2007. Are sea-level-rise trends along the coasts of the north Indian ocean consistent with global estimates? Glob. Planet. Change 57, 301–307. http://dx.doi.org/10.1016/j.gloplacha.2006.11.029.
Vega-Cendejas, M.E., de Santillana, M.H., 2019. Demersal fish assemblages and their diversity on the Yucatan continental shelf: Gulf of Mexico. Reg. Stud. Mar. Sci. 29, 100640. http://dx.doi.org/10.1016/j.rsma.2019.100640.
Vinayachandran, P.N., 2004. Summer cooling of the Arabian Sea during contrasting monsoons. Geophys. Res. Lett. 31. http://dx.doi.org/10.1029/2004GL019961.
Vinayachandran, P.N., Yamagata, T., 1998. Monsoon response of the sea around Sri Lanka: Generation of thermal domes and anticyclonic vortices. J. Phys. Oceanogr. 28, 1946–1960. http://dx.doi.org/10.1175/1520-0485(1998)028<1946:MROTSA>2.0.CO;2.
Wijayaratne, B., 2001. Coastal fisheries in Sri Lanka: Some recommendations for future management. United Nations Univ. Fish. Train. Program. 43.
WoRMS, 2018. WoRMS Editorial Board (2018) World Register of Marine Species [WWW Document]. http://dx.doi.org/10.14284/170.
Zubair, L., Yahiya, Z., Agalawatte, P., Lokuhetti, R., 2016. The El Niño event of 2015/16 in Sri Lanka predictions, preparedness, communication and impacts. Clim. Chang. Secr. Minist. Mahaweli Dev. Environ. 1, 51–149.