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Impact of tropical cyclone Ockhi on the marine fishery resource assemblages along the Kerala and Tamil Nadu coast, India

P. Punya[1,2]*, V. Kripa[1], Shelton Padua[1], K. S. Mohamed[1], R. Ranith[1], G. Gopika[1,2] and P. O. Nameer[2]
[1]ICAR-Central Marine Fisheries Research Institute, Kochi- 682 018, Kerala, India.
[2]College of Climate Change and Environmental Science, Kerala Agricultural University, Vellanikkara- 680 656, Kerala, India.

*Correspondence e-mail: punyaravichandran@gmail.com

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Original Article

Abstract

Extreme weather events such as tropical cyclones strongly influence marine fishery landings along the Indian coast. This paper assessed tropical cyclone Ockhi's impacts on the marine fishery resource assemblages along the Kerala and Tamil Nadu coasts. Apart from this, variation in environmental variables during the cyclone and their association with fishery was evaluated. The catch composition before, during, and after the Ockhi was determined using the SIMPER (Similarity Percentages) analysis. The species dissimilarity was high during and after the cyclone compared to the pre-cyclone data. The main environmental variations noticed during Ockhi were the decline in sea surface temperature, a hike in chlorophyll, salinity, and upwelling. Moreover, current speed and direction variations were observed during the cyclone month, and it might have badly affected fish recruitment. The study revealed the exponential changes in fish abundance during the cyclone and showed a sign of recovery in the post-cyclone period. This indicates that ecosystem changes due to such extreme events are not long-lasting, and the beneficial ecological changes in the habitats were helpful for the higher fish landings in the post-cyclone period.

***Keywords**: Cyclone, marine fishery, species dissimilarity, chlorophyll, upwelling, currents*

Introduction

Tropical cyclones are one of the most destructive natural disasters in the world. Globally, 1942 cyclones occurred in the past 50 years, leading to the death of 779,324 people and causing economic damage of US$ 1,407.6 billion (WMO, 2020). India has a mainland coastline of 7516 km, 75.8% of which (5,700 km) is vulnerable to cyclones and tsunamis (Chakraborty and Saha, 2017). The coastal zone is expected to be home to nearly 75% of the Asian population by 2025 (Dutta *et al.*, 2004), indicating the increased vulnerability of the coastal population and the fishing sector to such extreme events.

In India, marine fisheries contributed 5.93% of agricultural gross domestic product (GDP) in 2004-05 (Kumar *et al.*, 2010). India's Exclusive economic zone (EEZ) consists of highly diverse marine fishery resources with an annual harvestable potential of about 5.31 million metric tonnes (National Fisheries Policy, 2020). Sathianandan *et al.* (2012) studied the impact of Tsunami-2004 on the species diversity on the Tamil Nadu coast, and they reported a clear effect on species diversity along the Coromandel coast. Studies on the tropical storm's impact on reefs in Ritchie's Archipelago, Andaman, revealed that reefs suffered severe damage following the storm's passage. Also, high waves and increased sediment load by surface run-off caused significant damage to reefs in shallow and deeper regions (Krishnan *et al.*, 2013).

Cyclones and storm surge cause a drastic shift in environmental conditions, which can adversely affect marine organisms. Cyclone-induced phytoplankton blooms were identified with the advent of satellites (Lin *et al.*, 2003; Roy Chowdhury *et al.*, 2020). Lowering of ocean surface temperature in the path of cyclones has been observed. This may depend on the translation speed of the cyclones, ocean stratification, and the subsurface conditions of ocean waters (Singh and Roxy, 2020). Tropical cyclone Hudhud's effect on the biogeochemical processes in the Bay of Bengal was assessed using profiling float observations (Girishkumar *et al.*, 2019). They found an upsurge in chlorophyll and surface nitrate concentration and a reduced sub-surface dissolved oxygen during the cyclone period (Girishkumar *et al.*, 2019).

Tropical cyclone Ockhi originated as a low-pressure area on 28th November 2017 in the southwest Bay of Bengal. It rapidly intensified into a very severe cyclonic storm and devastated the southern coastal states of India (RSMC preliminary report, 2017). Cyclone Ockhi was an unusual cyclone, as was evident in its rapid intensification and unpredictable path. Also, Ockhi was the first very severe cyclone that formed in the Cape Comorin Sea after 1925 (Singh *et al.*, 2020). The physical damage and human fatalities due to the cyclone have already been recorded. A detailed study on the impact of Ockhi on marine fisheries will aid in understanding the cyclone's effects on marine fish landings. In this study, we attempted to provide detailed information on how Ockhi affected marine fishery resources. To assess the impact of Ockhi, two districts from Kerala *viz.* Thiruvananthapuram and Kollam, as well as a district from Tamil Nadu, *i.e.*, Kanyakumari, were selected. Variation in marine resource assemblages before, during, and after the cyclone was found using the Similarity Percentages analysis (SIMPER) in the PRIMER (Plymouth Routines in the Multivariate Ecological Research) software. The variation in environmental variables during the extreme event episode and their link with the fishery was also evaluated. The selected environmental parameters for the study were Sea Surface Temperature (SST), chlorophyll, salinity, rainfall, Local Temperature Anomaly (LTA), current direction, and velocity. These studies help to discover the sudden impact of extreme events on fishery abundance and composition. The studies on the effects of extreme climatic events on marine fisheries will be helpful in effective management measures and policies. Changes in the intensity, frequency and spatial extent of extreme climatic events will happen in the future owing to climate change (Seneviratne *et al.*, 2012). So, these kinds of studies help to make suitable adaptation and mitigation policies that will increase the resilience capacity of fishers to extreme events.

Material and methods

Fishery data

Monthly fishery data from 2007-2018, including catch and effort (number of units operated), were obtained from the National Marine Fisheries Data Centre (NMFDC) of CMFRI, Kochi. From this, monthly fishery data of Thiruvananthapuram, Kollam, and Kanyakumari districts which lay in the path of the cyclone Ockhi, were extracted and used for further analysis (Fig. 1). The stratified multi-stage random sampling technique is generally used to estimate the monthly fishery data (Srinath *et al.*, 2005). District-wise total fishery catch is calculated from the above fishery data and is used to estimate the relationship between environmental parameters and marine fishery. The total catch is the overall monthly fishery landings from all motorized and traditional crafts. Fishing crafts are mainly divided into mechanized, motorized, and non-motorized. The selected gears for this study are given in Table 1. The gears active during these periods were only considered for the study.

The fish catch varies depending on the area of operation and gear type. Suppose the gears operated in the nearshore areas, such as the non-motorized and outboard crafts and gears, fishery resources influenced by the coastal waters will be caught. The fish resources will differ in mechanized vessels because they catch fish in distant waters.

The gear mesh determines the size of the resources caught. Usually, small pelagic fishes are caught in the ring seines, while in hook and line gears, large pelagic fishes such as tunas and seer fishes are caught. Trawlers usually catch bottom resources such as shellfish, rays, and sharks (Pillai and Katiha, 2004).

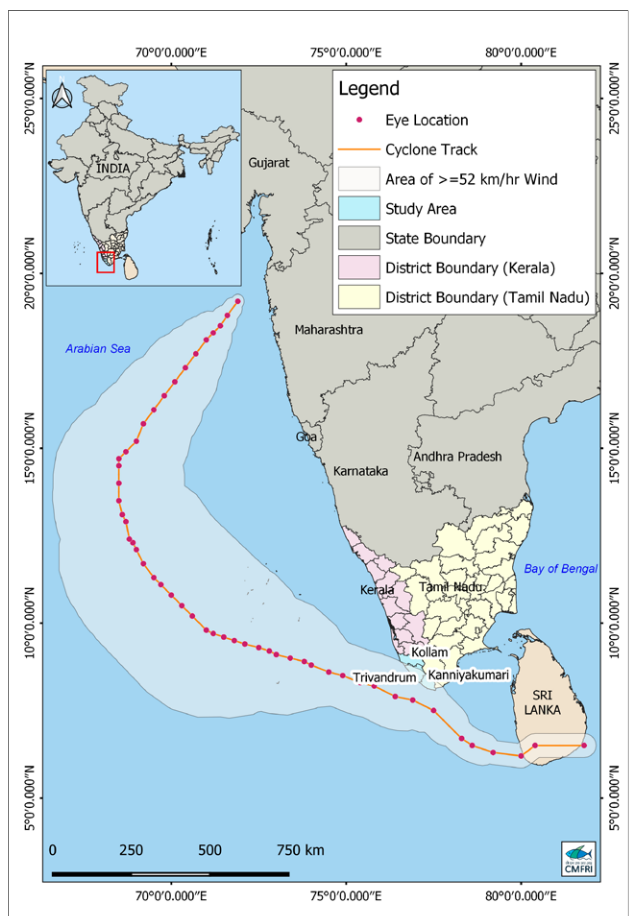

Fig. 1. Map showing the track of cyclone Ockhi and cyclone-affected districts selected for the study

Table 1. Types of gears operated along the Kerala and Tamil Nadu coasts during the Ockhi period

State	District	Gear Type
Kerala	Thiruvananthapuram	OBGN, OBHL, OBRS, NM, MRS
Kerala	Kollam	OBGN, OBHL, OBRS, NM, MRS, MDTN, MTN
Tamil Nadu	Kanyakumari	OBGN, OBHL, MDTN

OBGN: outboard gillnet, OBHL: outboard hook and line, OBRS: outboard ring seine, NM: non-motorized craft, MDTN: multi-day trawlnet, MTN: mechanized trawlnet, MRS: mechanized ring seine

On the Kanyakumari coast, mechanized and motorized vessels were operated during the study period. In Kerala, Outboard Gill Net (OBGN), Outboard Hook and Line (OBHL), Outboard Ring Seine (OBRS), Mechanized Ring Seine (MRS), and Non-Motorized (NM) crafts were operated in both Thiruvananthapuram and Kollam districts. In contrast, Multi-Day Trawl Net (MDTN) and Mechanized Trawl Net (MTN) crafts were active only on the Kollam coast. For cyclone Ockhi, the period from September to November 2017 was taken as pre-cyclone, December 2017 as cyclone, and January to March 2018 as the post-cyclone period.

Environment data

The SST data of 4 km spatial resolution and 1-month temporal resolution were collected from MODIS Aqua (Moderate Resolution Imaging Spectro-radiometer) sensor (OBPG, 2015). The monthly data on chlorophyll-*a* concentration from 2007-2018 were retrieved from the Ocean Color Climate Change Initiative (OC-CCI, 2020) website. Monthly sea surface salinity data were drawn from SODA3.4.2 (Simple Ocean Data Assimilation Ocean/Sea ice Reanalysis) and GODAS (Global Ocean Data Assimilation System) sensors (PSL, 2020; SODA, 2020). The SODA3.4.2 and OSCAR (Ocean Surface Current Analysis Real-time) sensors were used to retrieve the ocean currents data (PODAAC, 2020; SODA, 2020). Current speed and direction were derived from u and v components using the formula:

Current velocity $=\sqrt{(u^2+v^2)}$
Current direction $=180+[180^*\arctan2(u,v)]/\varpi$

Using Grapher 14 software, polar diagrams of the current velocity and direction were plotted. LTA is a coastal upwelling index, and it is derived by comparing inshore and offshore temperatures. The positive LTA values indicate the upwelling process, and the negative LTA values indicate coastal down-welling processes (Smitha *et al.*, 2008; Shah *et al.*, 2015). District-wise monthly rainfall data was downloaded from Open Government Data (OGD, 2020) Platform-data.gov.in website from 2007 to 2017. District-wise rainfall data in 2018 was accessed from the IMD website (IMD, 2020).

Data processing was done with R 4.0.3, QGIS 3.16.1, and MS Excel software. Using R software, environmental datasets falling within the shoreline area to a 100 m depth contour were extracted and used for the study. The data from 2007-2018 (12 years) were used to determine the climatological (normal) monthly mean values. The standardized anomaly was calculated using the given equation,

Standardized anomaly = (Actual value-Normal)/Standard Deviation

The cross-correlation method assessed the relationship between time-lagged environment and total fishery catch. The correlation coefficient r ranges from +1 to -1. +1 indicates a positive correlation, -1 indicates a negative correlation, and 0 shows no correlation (Evans, 1996).

Afterwards, the environmental variations during the cyclone period were analyzed. For that, 6-month data before and after the Ockhi were selected and compared with the normal monthly mean values, and the results were plotted as a line graph. Fish composition before, during, and after the cyclonic event was analyzed using PRIMER (Plymouth Routines in Multivariate Ecological Research) v.7 packages developed by the Plymouth Marine Laboratory, UK. Using the SIMPER module in PRIMER software, the percentage contribution of each species to the observed dissimilarity between the pre-cyclone and cyclone/post-cyclone period was found. We have used the Bray-Curtis similarity coefficient to quantify the similarity between all data pairs (Clarke, 1999).

Results and discussion

Influence of environmental parameters on the marine fish landings

Total fish catch in all affected districts significantly correlated with some of the oceanographic parameters. No significant correlation exists between total catch and SST standardized anomaly along the Thiruvananthapuram and Kanyakumari coasts (Table 2). A negative correlation was found between SST standardized anomaly and total catch across the coast of Kollam (Table 2).

Chlorophyll standardized anomaly positively correlated with total catch along the Thiruvananthapuram coast. A negative correlation was found between total catch and chlorophyll standardized anomaly along the Kollam coast with a lag of 3 months. The chlorophyll standardized anomaly and the entire fishery catch on the Kanyakumari coast showed a positive correlation with a lag of 6 months (Table 2).

LTA showed a positive correlation with a lag of 0 and 1 months and showed a negative correlation in 4, 5, and 6 lag

Table 2. Results of the cross-correlation analysis carried out between different oceanographic parameters and district-wise total catch.

Districts	Parameters	Lag in Months						
		0	1	2	3	4	5	6
	SSTA	-0.12	-0.06	-0.05	-0.06	-0.05	-0.03	-0.06
	CHLA	**0.22***	0.15	0.08	0.05	0.03	-0.0	-0.07
	RFA	-0.04	-0.01	0.07	0.02	0.05	0.06	-0.05
Thiruvananthapuram	SSSA	-0.04	0.08	0.15	0.16	0.07	0.1	0.12
	LTA	**0.52***	**0.35***	0.16	-0.07	**-0.25***	**-0.42***	**-0.45***
	CRMA	-0.12	-0.08	0.08	-0.01	-0.02	-0.03	-0.01
	CRDA	0.12	**0.19***	0.14	0.08	0.05	0.07	0.0
	SSTA	**-0.18***	-0.11	-0.08	0.0	0.05	0.08	0.03
	CHLA	-0.05	-0.04	-0.08	**-0.17***	-0.17	-0.04	-0.1
	RFA	0.02	-0.13	0.01	-0.01	-0.04	0.15	0.09
Kollam	SSSA	-0.04	-0.12	-0.14	-0.1	-0.11	-0.0	0.09
	LTA	**0.3***	**0.32***	**0.21***	0.05	-0.11	**-0.29***	**-0.25***
	CRMA	NA	NA	NA	NA	NA	NA	NA
	CRDA	NA	NA	NA	NA	NA	NA	NA
	SSTA	-0.08	-0.1	-0.07	0.03	-0.01	-0.01	0.04
	CHLA	0.13	0.14	0.03	0.11	0.05	0.15	**0.19***
	RFA	-0.01	0.03	-0.05	**0.22***	0.16	0.05	-0.01
Kanyakumari	SSSA	0.18	0.15	0.21	0.19	0.22	0.16	0.1
	LTA	**0.14***	0.04	**-0.04***	**-0.17***	**-0.1***	-0.07	-0.08
	CRMA	0.05	0.06	-0.09	-0.0	-0.1	0.01	0.03
	CRDA	-0.08	-0.11	0.1	-0.04	-0.14	-0.05	***-0.18**

* $p<0.05$ SSTA: sea surface temperature standardized anomaly, CHLA: chlorophyll standardized anomaly, RFA: rainfall standardized anomaly, SSSA: sea surface salinity standardized anomaly, LTA: local temperature anomaly, CRMA: current magnitude standardized anomaly, CRDA: standardized anomaly of the current direction

months along the Thiruvananthapuram coast. LTA showed a positive correlation in 0, 1, and 2 months and a negative correlation in 5, and 6 lag in months with the total catch of Kollam. In Kanyakumari, LTA has no significant correlation with fishery (Table 2).

No significant correlation exists between the standardized anomaly of rainfall and total catch along the Thiruvananthapuram, Kollam, and Kanyakumari districts. The standardized anomaly of salinity and rainfall also did not correlate with the fishery of Thiruvananthapuram and Kanyakumari coastal districts. Surface current data was unavailable for the Kollam coast to check collinearity (Table 2).

A positive correlation exists between standardized anomaly of current direction and total catch with a lag of 1 month along the Thiruvananthapuram coast. Also, a negative correlation exists between standardized anomalies of the current direction and the total fishery catch of Kanyakumari with a lag of 6 months (Table 2).

Environmental changes during Ockhi along the Kerala coast

The variation in environmental parameters before, during, and after the months of the cyclone was analyzed along the Thiruvananthapuram, Kollam, and Kanyakumari coastal districts. In Thiruvananthapuram and Kollam districts, SST slightly decreased in December compared to the pre-cyclone month (*i.e.*, November). It again sharply reduced in the post-cyclone month (*i.e.*, January) (Fig. 2). Compared to the pre-cyclone month, SST slightly decreased in December 2017 along the Kanyakumari coast (Fig. 8a).

Compared to normal, chlorophyll slightly increased on Thiruvananthapuram, Kollam, and Kanyakumari coast during the cyclone period (Fig. 3 and 8b). LTA was positive (0.05), indicating an upwelling on the Thiruvananthapuram coast. But in Kollam, LTA was nearly zero. In January, LTA became positive and intensified on both coasts (Fig. 5). LTA was positive (+0.51) in the cyclone period along the Kanyakumari coast (Fig. 9b).

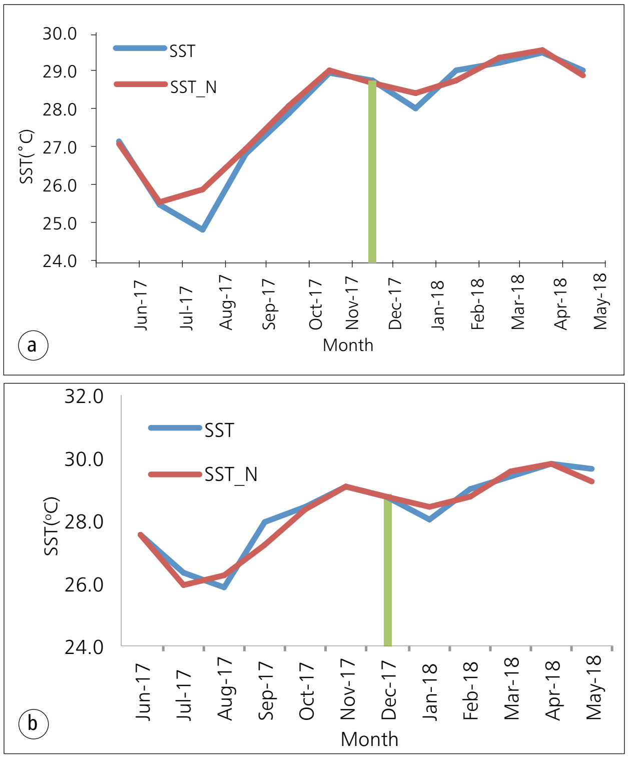

Fig. 2. Monthly mean SST (sea surface temperature) from June 2017 to May 2018; a) Thiruvananthapuram b) Kollam [green bar indicates the time of occurrence of cyclone Ockhi]; SST_N: month-wise 15-year average sea surface temperature

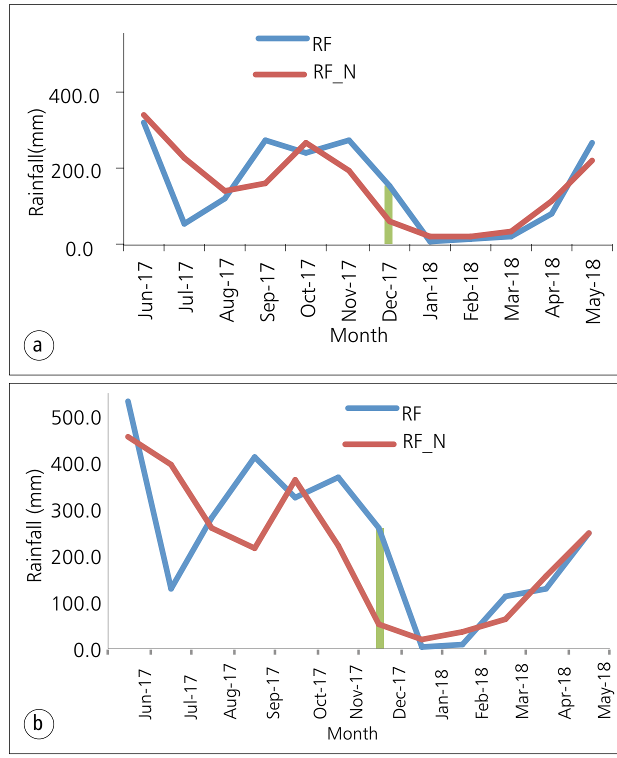

Fig. 4. Monthly rainfall (RF) from June 2017 to May 2018; a) Thiruvananthapuram b) Kollam (green bar indicates the time of occurrence of cyclone Ockhi); RF_N: month-wise 15-year average rainfall

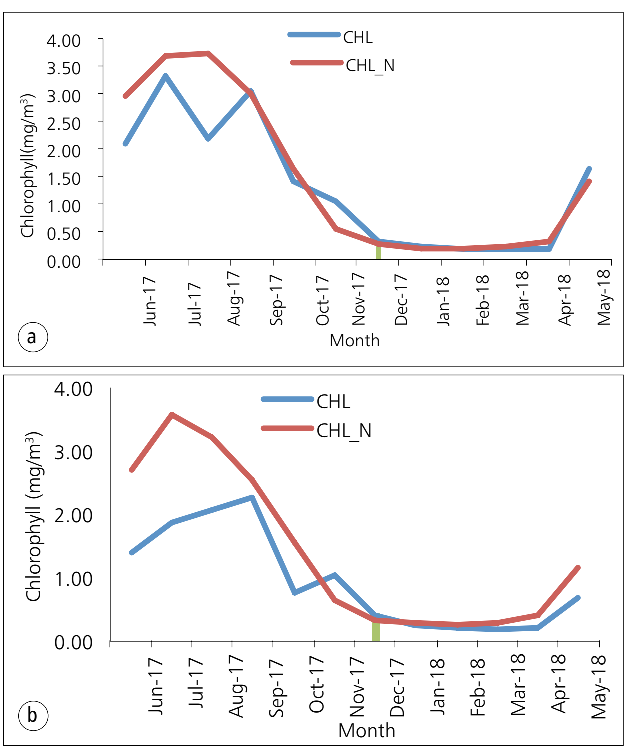

Fig. 3. Monthly mean chlorophyll (CHL) from June 2017 to May 2018; a) Thiruvananthapuram b) Kollam (green bar indicates the time of occurrence of cyclone Ockhi); CHL_N: month-wise 15-year average chlorophyll

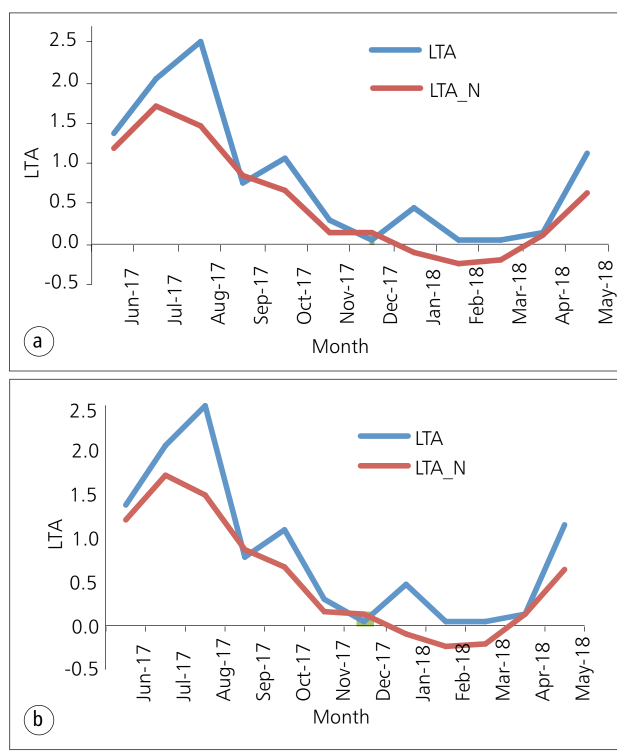

Fig. 5. Monthly mean local temperature anomaly (LTA) from June 2017 to May 2018; a) Thiruvananthapuram b) Kollam [green bar indicates the time of occurrence of cyclone Ockhi]; LTA_N: month-wise 15-year average local temperature anomaly

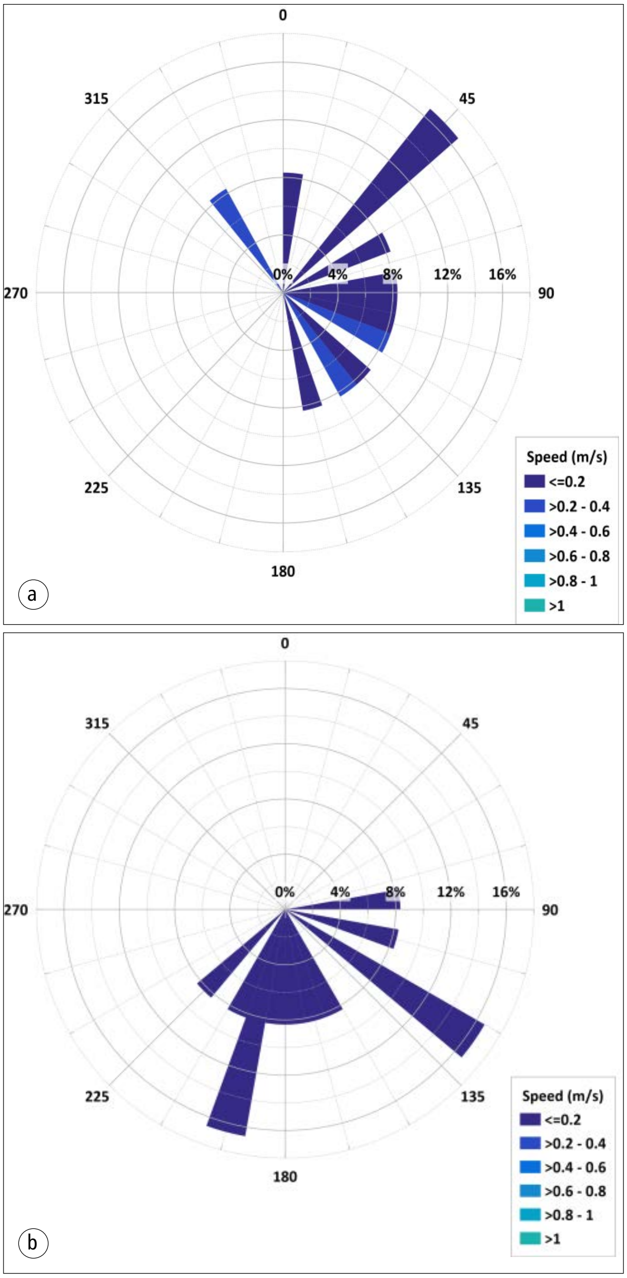

Fig. 6. Polar diagram showing current velocity and direction a) current velocity and direction during Ockhi along the Thiruvananthapuram coast b) month-wise 15-year average current speed and direction along the Thiruvananthapuram coast

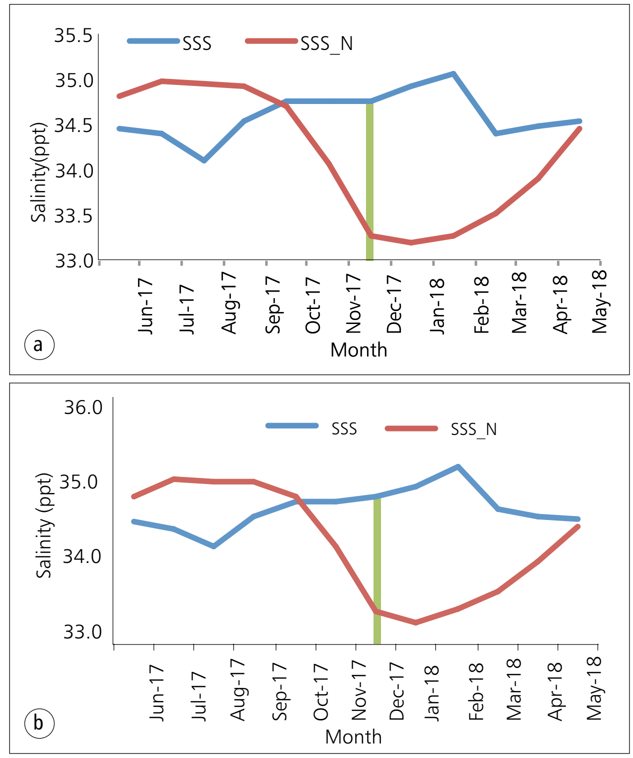

Fig. 7. Monthly mean salinity (SSS) from June 2017 to May 2018; a) Thiruvananthapuram b) Kollam (green bar indicates the time of occurrence of cyclone Ockhi); SSS_N: month-wise 15-year average salinity

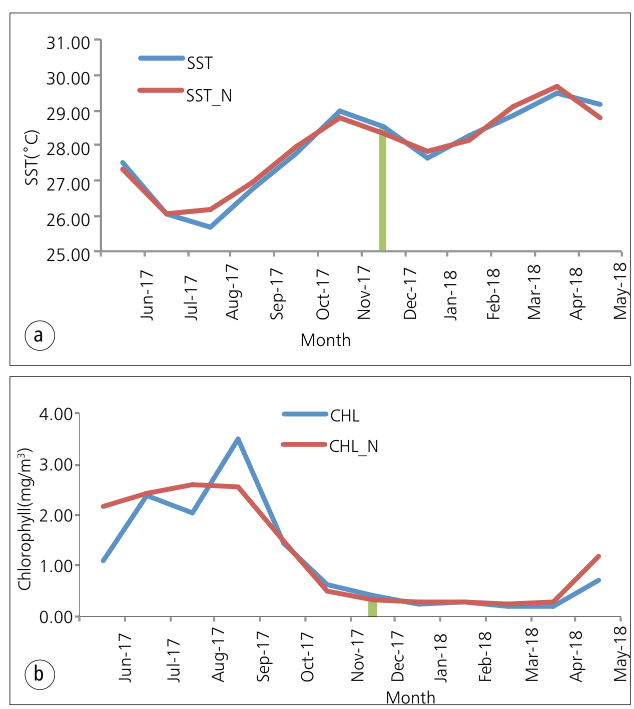

Fig. 8. Monthly data from June 2017 to May 2018 in Kanyakumari coast a) sea surface temperature (SST) b) chlorophyll (CHL) (green bar indicate the time of occurrence of cyclone Ockhi); SST_N: month-wise 15-year average sea surface temperature, CHL_N: month-wise 15-year average chlorophyll

On the Thiruvananthapuram and Kollam coasts, rainfall showed an increase in December (Fig.4). Also, monthly rainfall showed a peak in December along the Kanyakumari coast (Fig. 9a). Salinity was very high (33.2 to 34.7 ppm) on Thiruvananthapuram, and Kollam coasts during the cyclone period (Fig. 7). But the salinity was low on the Kanyakumari coast compared to the pre-cyclone month salinity data (*i.e.*, November 2017) (Fig. 11).

During the cyclone month, surface current velocity and direction

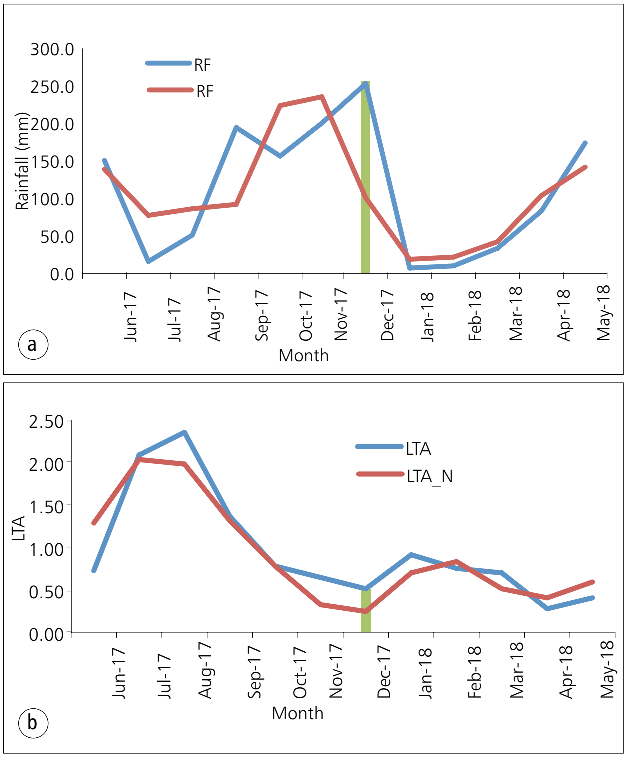

Fig. 9. Monthly data from June 2017 to May 2018 in Kanyakumari coast a) rainfall (RF) b) local temperature anomaly (LTA) (green bar indicate the time of occurrence of cyclone Ockhi); RF_N: month-wise 15-year average rainfall, LTA_N: month-wise 15-year average local temperature anomaly

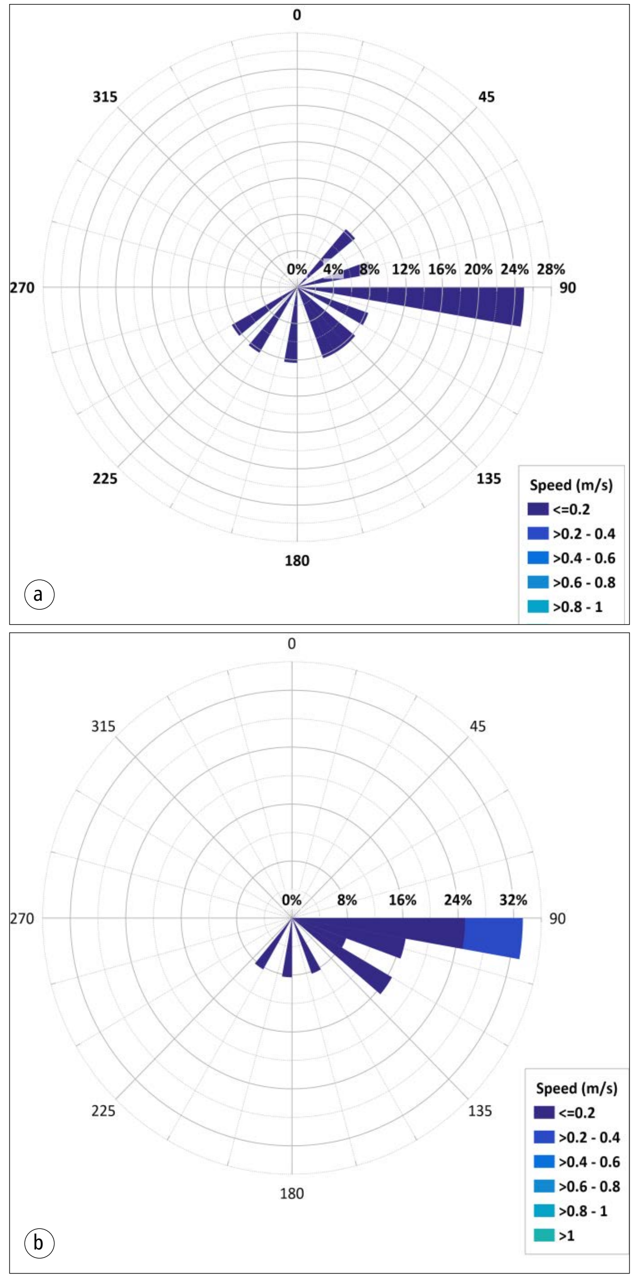

Fig.10 Polar diagram showing monthly current speed and direction; a) current speed and direction during Ockhi b) month-wise 15-year average current speed and direction along the Kanyakumari coast.

varied from normal and current velocity considerably increased along the Thiruvananthapuram coast (Fig.6). The surface current data was unavailable for the Kollam coast. During the cyclone period, current velocity decreased from normal along the Kanyakumari coast (Fig. 10). Additionally, the current direction showed slight variation in the cyclone period (Fig. 10).

Girishkumar *et al.* (2019) reveal that the strength of oceanographic changes during cyclones depends on the properties of the storm and the prevailing upper ocean structures, such as the presence of mesoscale eddies. Research on cyclone-induced productivity in the southwestern Bay of Bengal from November-December 2000 found a maximum SST drop of 2 °C persist 14 to 16 days after the cyclone (Rao *et al.*, 2006). In this study, we have taken the monthly data of environmental variables. So, the sudden and noticeable fluctuations in environmental variables during the cyclone period were not much visible in our analysis.

The major environmental variations noticed during Ockhi were the lowering of SST, increase in chlorophyll, rainfall, and salinity. Also, variations in LTA and surface currents were noted on all coasts. SST slightly decreased in all three affected districts during December. In India, a lowering of SST by 3 °C was reported during the Arabian Sea cyclone in 1998 (Premkumar *et al.*, 2000). In addition to the reduction in SST, there was an increase in sea surface salinity on coasts during the cyclone period. In earlier studies, enhanced salinity was observed in the Bay of Bengal after the cyclone's passage (Maneesha *et al.*, 2012; Mandal *et al.*, 2018; Chaudhuri *et al.*, 2019). The intense mixing of water during the course of cyclones enhances the intrusion of high-saline water from the subsurface into the surface ocean (Singh and Roxy, 2020). Besides this, chlorophyll concentration also increased on all coasts either during the cyclone or post-cyclone month, which was favourable for the fishery. Earlier

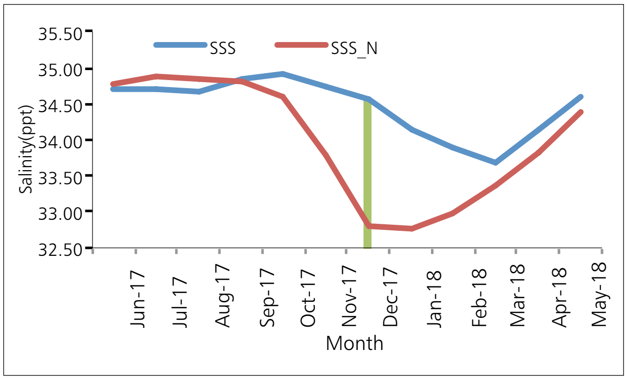

Fig.11. Monthly mean salinity (SSS) from June 2017 to May 2018 along the Kanyakumari coast (green bar indicates the time of occurrence of cyclone Ockhi); SSS_N: month-wise 15-year average salinity

studies on the impacts of cyclones show that tropical cyclone is a vital mechanism to pump nutrients into the upper euphotic zone, leading to significant phytoplankton blooms and an increase in the ocean's primary production (Wang *et al.*, 2011). This increase in chlorophyll concentration is mainly due to the strong vertical mixing and upwelling during cyclones (Singh and Roxy, 2020). Here also, we observed positive LTA values in all affected coasts either during or after the cyclone, which indicates the cyclone-induced upwelling along the shores.

During and after the cyclone, the velocity of the surface current was considerably high on the Thiruvananthapuram coast. The current direction had changed slightly along the affected part of the southwest and southeast coast. Unlike the Thiruvananthapuram coast, current velocity decreased along the Kanyakumari coast. This variation in current speed and direction would have affected the marine resources. Cross-correlation analysis indicates a significant connection between the current direction and total fisheries along the affected coasts with a 1 and 6 months lag. Besides, large numbers of juvenile young Atlantic croakers were observed in the Chesapeake Bay region after Hurricane Isabel in 2003 (Roman *et al.*, 2005). Since November and December are the periods when most demersal fishes spawn along the southwest coast, the impact of this change in current velocity and direction is a matter of concern. It could have transported the larvae and juvenile fishes and affected their recruitment. The variation in current velocity and direction found during the cyclone period can lead to the drifting away of eggs, larvae, and juvenile fishes, which may impact the recruitment of the fishery after the cyclone.

Impact on marine fishery assemblages off Kerala

The analysis was done using PRIMER software to identify the changes in resource assemblages in the Ockhi-impacted districts. We found a high percentage deviation during and after the cyclone (Figs. 12 and 13).

In MRS-operated areas, percentage dissimilarity was highest at Thiruvananthapuram. The percentage dissimilarity of 97.53% was noted between the pre-cyclone and cyclone periods, which reduced to 87.12% during the cyclone and the post-cyclone periods. The percentage dissimilarity was 75.73% between the pre-cyclone and post-cyclone periods along the

Table 3. Results of SIMPER test on resources caught by MRS (mechanized ring seine) in the cyclone-affected districts of Kerala (resources which contribute up to 50% cumulate percentage dissimilarity have been listed)

Affected district	Average dissimilarity	Species/Group	Group 1 Av. Abundance	Group 2 Av. Abundance	Av. Dissimilarity	Percentage contribution
Thiruvananthapuram	pre-cyclone and cyclone–97.53%	Indian mackerel	154.8	2.3	31.38	32.17
		Barracudas	104.9	0	21.58	22.13
		Stolephorus spp.	63.3	0	13.02	13.35
	cyclone and the post-cyclone–87.12%	Lesser sardines	2	23.8	23.02	26.42
		Oil sardine	1.3	20.9	20.7	23.76
		Indian mackerel	2.3	15.4	13.83	15.88
	pre-cyclone and the post-cyclone-75.73%	Indian mackerel	154.8	15.4	24.52	32.38
		Barracudas	104.9	0	18.45	24.37
		Stolephorus spp.	63.3	0	11.13	14.7
Kollam	pre-cyclone and cyclone–58.91%	Oil sardine	878.2	301.8	16.75	28.43
		Indian mackerel	456.6	4.8	13.13	22.28
		Stolephorus spp.	400.1	53.2	10.08	17.11
	cyclone and the post-cyclone–58.34%	*Stolephorus* spp.	53.2	478.3	22.03	37.76
		Oil sardine	301.8	635.2	17.28	29.62
		Lesser sardines	326.6	14.8	16.16	27.7
	pre-cyclone and the post-cyclone-42.44%	Indian mackerel	456.6	16.3	11.2	26.39
		Lesser sardines	313.7	14.8	7.6	17.91
		Oil sardine	878.2	635.2	6.18	14.56

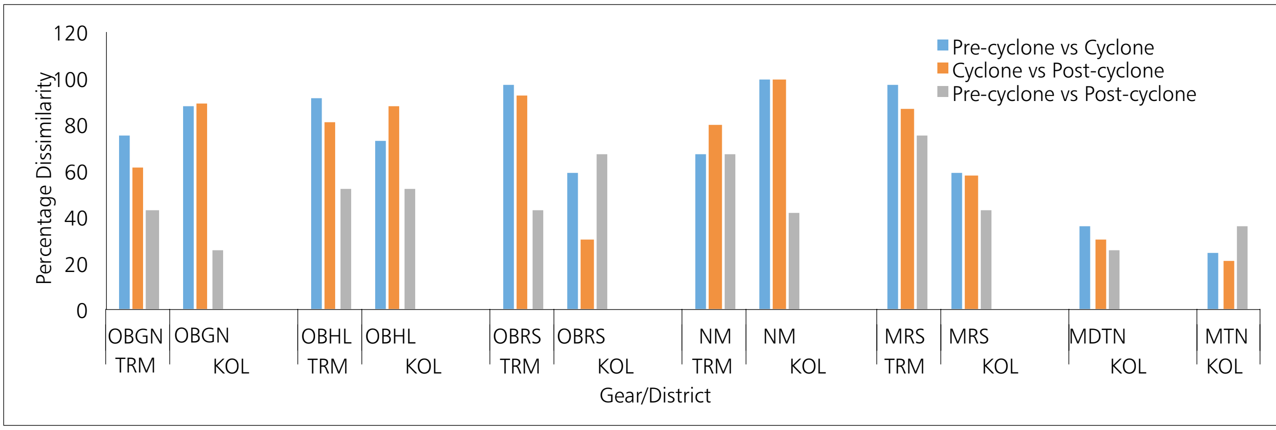

Fig. 12. Percentage dissimilarity in the species/group composition of landings by different gears operated in the cyclone Ockhi affected districts of Kerala

(TRM: Thiruvananthapuram, KOL: Kollam, OBGN: outboard gillnet, OBHL: outboard hook and line, OBRS: outboard ringseine, NM: non-motorized gear, MRS: mechanized ringseine, MTN: mechanized trawlnet, MDTN: multiday trawlnet)

Table 4. Results of SIMPER test on resources caught by OBGN (outboard gillnet) in the cyclone-affected districts of Kerala (resources which contribute up to 50% cumulate percentage dissimilarity have been listed)

Affected district	Average dissimilarity	Species/Group	Group 1 Av. abundance	Group 2 Av. Abundance	Av. dissimilarity	Percentage contribution
Thiruvananthapuram	pre-cyclone and cyclone–75.59%	Indian mackerel	297.1	55.8	13.29	17.58
		Ribbon fishes	230.6	0	12.7	16.8
		Auxis spp.	246.8	58.3	10.38	13.74
		E. affinis	196.4	36.6	8.8	11.64
	cyclone and the post-cyclone–61.28%	Indian mackerel	55.8	197.1	11.44	18.67
		Other carangids	41.5	178.8	11.12	18.14
		Other tunnies	5.6	132.8	10.3	16.81
		E. affinis	36.6	99.4	5.08	8.3
	pre-cyclone and the post-cyclone–43.32%	Ribbon fishes	230.6	14	8.47	19.56
		Auxis spp.	246.8	81.8	6.45	14.9
		Indian mackerel	297.1	197.1	3.91	9.03
		E. affinis	196.4	99.4	3.79	8.76
		Other carangids	102.7	178.8	2.98	6.87
Kollam	pre-cyclone and cyclone–87.8%	*K. pelamis*	64.4	0	10.34	11.78
		E. affinis	69.8	6.9	10.1	11.51
		Oil sardine	73.6	12	9.89	11.27
		Indian mackerel	66.6	5.8	9.76	11.12
		Auxis spp.	64.1	4.5	9.57	10.9
	cyclone and the post-cyclone–89.11%	Oil sardine	12	118.7	15.74	17.66
		E. affinis	6.9	93	12.7	14.25
		K. pelamis	0	81.6	12.04	13.51
		Indian mackerel	5.8	79.9	10.93	12.27
	pre-cyclone and the post-cyclone–25.52%	Oil sardine	73.6	118.7	3.68	14.44
		Auxis spp.	64.1	27.7	2.97	11.65
		Lesser sardines	6.2	42.1	2.93	11.49
		E. affinis	69.8	93	1.9	7.43
		Bill Fishes	32.2	53.7	1.76	6.88

Thiruvananthapuram coast (Fig.12). The main fish resource caught in the pre-cyclone period was Indian mackerel, followed by barracudas. During the cyclone period, Indian mackerel catch reduced. Also, barracudas, *Stolephorus* spp. and other carangids (67.66%) were not caught during the month of the cyclone. A slight increase in the catch of lesser sardines, oil sardines, and Indian mackerel was noticed in the post-cyclone period (Table 3).

The percentage dissimilarity in species assemblages in the MRS gear was much lower at Kollam than at Thiruvananthapuram. The decline in resources during the cyclone and the post-cyclone was notable. During the cyclone period, there was a decrease in the catch of oil sardine, Indian mackerel, and *Stolephorus* spp. The percentage dissimilarity was almost the same between the cyclone and the post-cyclone periods (57.34%). The percentage dissimilarity was 42.44% between the pre-cyclone and the post-cyclone periods. There was an increase in the catch of *Stolephorus* spp. (37.76%) and oil sardine (29.62%) during the post-cyclone period. (Fig. 12; Table 3).

In Thiruvananthapuram, the percentage dissimilarity between the pre-cyclone and cyclone periods was 75.59% in OBGN gear. Indian mackerel, ribbon fishes, *Auxis* spp. and *E. affinis* were the primary resources contributing to the dissimilarity. The ribbon fishes were not caught during the entire cyclone month. Percentage dissimilarity between the cyclone and the post-cyclone was higher (61.28%), and this was mainly due to the increased landings of Indian mackerel, other carangids, *E. affinis*, and other tunnies. Percentage dissimilarity between the pre-cyclone and the post-cyclone period was 43.32% in OBGN along the Thiruvananthapuram coast (Fig.12; Table 4).

In the Kollam district, there was very high dissimilarity in OBGN gear during the cyclone and pre-cyclone periods (87.8%) and the cyclone and post-cyclone periods (89.11%). However, the dissimilarity was low (25.52%) when the resources of the pre-cyclone and the post-cyclone periods were compared (Fig.12). *K. pelamis*, which formed an important catch in the pre-cyclone period, was not caught during the cyclone period. A high catch of oil sardine led to a dissimilarity of 17.66% between the cyclone and the post-cyclone period. *E. affinis* and Indian mackerel catch also increased in the post-cyclone period along the Kollam coast (Table 4).

In OBHL gear, dissimilarity in the resource assemblage was high (91.05%) between the pre-cyclone and cyclone periods along the Thiruvananthapuram district. The main reason was the reduction in *Auxis* spp. landings (Fig. 12; Table 5). There was a high dissimilarity between the cyclone and the post-cyclone period (81.51%). The Shark's landings were not reported during

Table 5. Results of SIMPER test on resources caught by OBHL (outboard hook and line) in the cyclone-affected districts of Kerala (resources which contribute up to 50% cumulate percentage dissimilarity have been listed)

Affected district	Average dissimilarity	Species/Group	Group 1 Av. Abundance	Group 2 Av. Abundance	Av. Dissimilarity	Percentage contribution
Thiruvananthapuram	pre-cyclone and cyclone–91.05%	*Auxis* spp.	175.8	5.1	28.81	31.64
		E. affinis	60.3	6.4	9.1	9.99
		Ribbon fishes	44	0	7.43	8.16
		Other carangids	44.2	3.3	6.9	7.58
	cyclone and the post-cyclone–81.51%	Sharks	0	39.4	12.92	15.85
		Other carangids	3.3	42.4	12.82	15.73
		Auxis spp.	5.1	37.2	10.52	12.91
		Rock cods	2	23.2	6.95	8.53
	pre-cyclone and the post-cyclone-52.59%	*Auxis* spp.	175.8	37.2	16.48	31.34
		Sharks	0	39.4	4.68	8.91
		E. affinis	60.3	21	4.67	8.89
		Ribbon fishes	44	4.9	4.65	8.84
Kollam	pre-cyclone and cyclone–73.01%	*E. affinis*	28.9	1.8	29.98	41.06
		K. pelamis	21.4	0	23.67	32.42
	cyclone and the post-cyclone–87.87%	*E. affinis*	1.8	70.7	28.62	32.58
		K. pelamis	0	47.4	19.69	22.41
	pre-cyclone and the post-cyclone-51.84%	*E. affinis*	28.9	70.7	13.85	26.71
		K. pelamis	21.4	47.4	8.61	16.61
		Half beaks and full beaks	0.1	12	3.94	7.6

Table 6. Results of SIMPER test on resources caught by NM (non-motorized) in the cyclone-affected districts of Kerala (resources which contribute up to 50% cumulate percentage dissimilarity have been listed)

Affected district	Average dissimilarity	Species/Group	Group 1 Av. Abundance	Group 2 Av. abundance	Av. Dissimilarity	Percentage contribution
Thiruvananthapuram	pre-cyclone and cyclone–66.63%	*Stolephorus* spp.	31	3.8	16.69	25.05
		Silverbellies	19.9	0.3	12.02	18.05
		Crabs	17.3	0.5	10.31	15.47
	cyclone and the post-cyclone–79.65%	Bivalves	0	152.8	47.25	59.32
		Silverbellies	0.3	40.6	12.46	15.64
	pre-cyclone and the post-cyclone-67.43%	Bivalves	0	152.8	38.1	56.51
		Stolephorus spp.	31	6.5	6.11	9.06
Kollam	pre-cyclone and cyclone–100%	Crabs	10.2	0	21.29	21.29
		Croakers	6.3	0	13.15	13.15
		Cuttlefish	5	0	10.44	10.44
		Lizard Fishes	3.6	0	7.52	7.52
	cyclone and the post-cyclone–100%	Croakers	0	9.5	21.94	21.94
		Cuttlefish	0	8.3	19.17	19.17
		Lesser sardines	0	8.3	19.17	19.17
	pre-cyclone and the post-cyclone-42.32%	Crabs	10.2	4.8	5.92	13.99
		Lesser sardines	3.1	8.3	5.7	13.47
		Cuttlefish	5	8.3	3.62	8.55
		Barracudas	3.2	0	3.51	8.29
		Croakers	6.3	9.5	3.51	8.29

the cyclone month, and their catch was noted during the post-cyclone period (15.85%) (Table 5).

In Kollam, the dissimilarity was highest (87.87%) between the cyclone and the post-cyclone periods in OBHL gear. The increased catch of *E. affinis* and the absence of *K. pelamis* were noted during the cyclone period (73.48%). The total dissimilarity was 51.84% between the pre-and post-cyclone assemblage (Fig. 12; Table 5).

NM crafts are operated in the nearshore waters. The dissimilarity was high in all three categories, such as pre-cyclone and cyclone; cyclone and post-cyclone, and between pre- and post-cyclone periods along the Thiruvananthapuram district. The estimated percentage dissimilarity was 66.63, 79.65, and 67.43%, respectively (Fig. 12). *Stolephorus* spp., silver bellies, and crabs were the main fish resources during the pre-cyclone period. Their catch declined in the cyclone month. Bivalves that occurred in the catch during the post-cyclone period contributed 59.32% dissimilarity. Also, the silver bellies catch was high in the post-cyclone period (Table 6).

NM fishing crafts were not operated in the Kollam district during the cyclone period. Since there was no fishing during the cyclone period by these crafts, only the pre-cyclone and the post-cyclone variation were estimated, and there was 42.32% dissimilarity (Fig. 12 and Table 6).

In OBRS gear, the dissimilarity in resource assemblage between pre-cyclone and cyclone was 96.64%, and between the cyclone and the post-cyclone was 92.34% along the Thiruvananthapuram district. This was mainly due to a decrease in landings of *Stolephorus* spp. (42.13%) during the cyclone and its re-back in the post-cyclone period (69.91%). Oil sardine was one of the main catches in OBRS in the pre-cyclone period, which was also not caught during the month of Ockhi. Moreover, increased catch of lesser sardines was also reported during the post-cyclone period (Fig. 12; Table 7).

The percentage dissimilarity between the cyclone and pre-cyclone species assemblage in the OBRS operating grounds off Kollam was 59.31%, mainly due to variations in *Stolephorus* spp. (46.4%) and oil sardine (18.41%) landings. The dissimilarity percentage between the cyclone and the post-cyclone period was 30.32%, mainly due to the abundance of lesser sardines during the cyclone period (57.62%). Higher dissimilarity in fish resource assemblage of the pre-cyclone and post-cyclone periods was due to the decreased catch of *Stolephorus* spp. (42.39%) and oil sardine (16.52%) in the post-cyclone period (Fig. 12 and Table 7).

Table 7. Results of SIMPER test on resources caught by OBRS (outboard ring seine) in the cyclone-affected districts of Kerala (resources which contribute up to 50% cumulate percentage dissimilarity have been listed)

Affected district	Average dissimilarity	Species/Group	Group 1 Av. Abundance	Group 2 Av. Abundance	Av. Dissimilarity	Percentage contribution
Thiruvananthapuram	pre-cyclone and cyclone–96.64%	*Stolephorus* spp.	196.5	2.8	40.71	42.13
		Oil sardine	101.1	0	21.25	21.99
	cyclone and the post-cyclone–92.3%	*Stolephorus* spp.	2.8	143.6	64.53	69.91
		Lesser sardines	0.9	12.9	5.5	5.96
	Pre-cyclone and The post-cyclone–42.73%	Oil sardine	101.1	10.5	13.38	31.31
		Indian mackerel	74.8	9.3	9.67	22.63
		Stolephorus spp.	196.5	143.6	7.81	18.28
Kollam	pre-cyclone and cyclone–59.31%	*Stolephorus* spp.	572.4	107.6	27.52	46.4
		Oil sardine	275.1	90.7	10.92	18.41
	cyclone and the post-cyclone–30.32%	Lesser sardines	124.8	3.8	17.47	57.62
		Other perches	0	38.1	5.5	18.14
	pre-cyclone and the post-cyclone–67.66%	*Stolephorus* spp.	572.4	104	28.68	42.39
		Oil sardine	275.1	92.6	11.17	16.52

Table 8. Results of SIMPER test on resources caught by MDTN (multi-day trawlnet) in the cyclone-affected districts of Kerala (resources which contribute up to 50% cumulate percentage dissimilarity have been listed)

Affected district	Average dissimilarity	Species/Group	Group 1 Av. Abundance	Group 2 Av. Abundance	Av. Dissimilarity	Percentage contribution
Kollam	pre-cyclone and cyclone–36.17%	Penaeid shrimps	750.7	415.3	4.25	11.74
		Scads	405	102.5	3.83	10.59
		Squids	421.4	129.9	3.69	10.2
		Ribbon fishes	329.3	41.5	3.64	10.07
		Lizard Fishes	495.6	226.6	3.4	9.41
	cyclone and the post-cyclone–30.53%	Scads	102.5	677	7.1	23.24
		Penaeid shrimps	415.3	723.9	3.81	12.49
		Non-penaeid shrimps	233.7	523.7	3.58	11.73
		Other carangids	135.3	393.7	3.19	10.45
	pre-cyclone and the post-cyclone–26.12%	Ribbon fishes	329.3	43	2.79	10.67
		Scads	405	677	2.65	10.14
		Lizard Fishes	495.6	268.6	2.21	8.46
		Other carangids	171.9	393.7	2.16	8.27
		Threadfin breams	560.5	764.8	1.99	7.61
		Squids	421.4	220.1	1.96	7.5

Trawls were not operated in Thiruvananthapuram, but there were trawls in Kollam (MDTN and MTN). The marine resource assemblage in the fishing area off Kollam by MDTN had a dissimilarity of 36.17% between the cyclone and pre-cyclone, mainly contributed by the decline in penaeid shrimps, scads, squids, ribbon fishes, and lizardfish landings. The dissimilarity was much lower (30.53%) between the cyclone and the post-cyclone period, and this was contributed by the increase in the catch of cads, penaeid shrimps, and non-penaeid shrimps. The pre-cyclone and the post-cyclone species assemblage dissimilarity was 26.12% (Fig. 12 and Table 8).

The percentage dissimilarity during the cyclone and pre-cyclone period in the MTN-operated areas was 24.97%, contributed mainly by the decline in the catch of *Stolephorus* spp. and ribbon fishes. This further reduced to 21.2% during the cyclone and the post-cyclone periods. However, the dissimilarity was 35% compared to the pre- and post-cyclone assemblages, mainly due to the decline in *Stolephorus* spp., ribbon fishes, and cuttlefish catches (Fig.12 and Table 9). During the cyclone period, major fish resources available in the pre-cyclone period were not caught or in low abundance along the Kerala coast. These fish resources

Table 9. Results of SIMPER test on resources caught by MTN (mechanized trawlnet) in the cyclone-affected districts of Kerala (resources which contribute up to 50% cumulate percentage dissimilarity have been listed)

Affected district	Average dissimilarity	Species/Group	Group 1 Av. Abundance	Group 2 Av. Abundance	Av. Dissimilarity	Percentage contribution
Kollam	Pre-cyclone and Cyclone–24.97%	*Stolephorus* spp.	28.2	4.4	6.47	25.9
		Ribbon fishes	13.6	0	3.69	14.8
		Lizard Fishes	8.4	0.1	2.25	9.03
		Lesser sardines	8.4	1	2.01	8.05
	Cyclone and The post-cyclone–21.2%	Miscellaneous	7.6	20.1	4.51	21.29
		Cuttlefish	8	0	2.89	13.63
		Penaeid shrimps	48.5	42.3	2.24	10.56
		Silverbellies	5.5	10	1.63	7.67
	Pre-cyclone and The post-cyclone–35.51%	*Stolephorus* spp.	28.2	0.7	7.48	21.06
		Miscellaneous	8.3	20.1	3.21	9.04
		Ribbon fishes	13.6	2	3.15	8.88
		Cuttlefish	11.5	0	3.13	8.81
		Penaeid shrimps	51.6	42.3	2.53	7.12

started appearing after the cyclone when the conditions started becoming normal.

Impacts of Ockhi on fishery assemblage off Tamil Nadu

Only the Kanyakumari district in Tamil Nadu was selected for the study. In the SIMPER test, all three gears operated along the Kanyakumari coast showed a high variation during the cyclone and the post-cyclone periods. Comparatively, the dissimilarity was much lower between the pre-cyclone and post-cyclone periods (Fig. 13).

The highest dissimilarity (90.1%) was observed in the MDTN catch, especially during the cyclone and the post-cyclone period. The species assemblage in MDTN along the Kanyakumari coast was also dissimilar before and during the cyclone period (88.31%). The major resources contributing to the difference were oil sardines and Indian mackerel. Several fishes, such as wolf herring and other perches that had formed an important part of the pre-cyclone catch, were not caught during the cyclone period. The species assemblage during the cyclone and the post-cyclone was also highly dissimilar. Croakers, Indian mackerel, scads, and other carangids which were present in the catch during the post-cyclone period were not caught during the cyclone month. The species assemblage of the pre- and post-cyclone periods also showed high variation (67.18%). A major contributor to the pre-cyclone catch was oil sardines, and oil sardine landings were not reported during the post-cyclone months (Fig.13 and Table 10).

The dissimilarity was high (80.03%) in OBGN gear when the pre-cyclone and cyclone assemblages were compared. The dissimilarity was 45.18% between the cyclone and the post-cyclone period. However, there was 67.77% dissimilarity when we compared the pre-cyclone and the post-cyclone period catches. The oil sardine, big-jawed jumper, and ribbon fish landings were not observed in the cyclone period. Also, the Indian mackerel and lesser sardines catch decreased during the cyclone period. The dissimilarity between the cyclone and the post-cyclone assemblages was comparatively lower (45.18%). The occurrence of *E. affinis* and other clupeids in the post-cyclone catch contributed to 24.25% dissimilarity. Oil sardines had formed the major part of the assemblage during the pre-cyclone period. Though this species occurred in the catch during the post-cyclone, their reduced catch led to a dissimilarity of 9.39% (Fig. 13 and Table 10).

The percentage dissimilarity between the cyclone and pre-cyclone period was high (64.75%) in OBHL gear which reduced to 49.45% in the cyclone and the post-cyclone period. However,

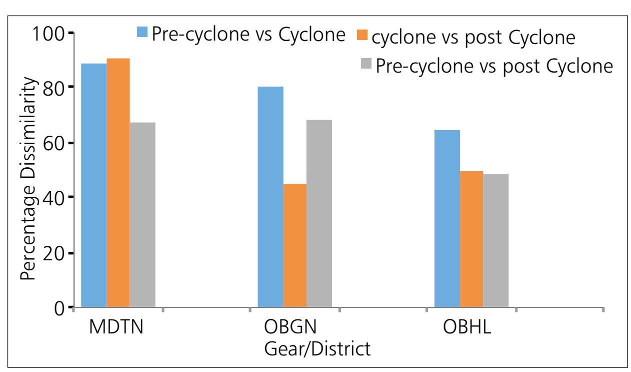

Fig. 13. Percentage dissimilarity in the species/group composition of landings by different gears operated in the Kanyakumari district during cyclone Ockhi

Table 10. Results of SIMPER test on resources caught by MDTN (multiday trawlnet), OBGN (outboard gillnet), and OBHL (outboard hook and line) in the cyclone-affected districts of Kanyakumari (resources which contribute up to 50% cumulate percentage dissimilarity have been listed)

Gear type	Average dissimilarity	Species/Group	Group 1 Av. Abundance	Group 2 Av. Abundance	Av. Dissimilarity	Percentage contribution
MDTN	pre-cyclone and cyclone–88.31%	Oil sardine	46.78	0	12.25	13.87
		Indian mackerel	35.04	0	9.18	10.39
		Miscellaneous	28.48	6.88	5.66	6.4
		Wolf herring	19.02	0	4.98	5.64
		Other perches	18.84	0	4.93	5.59
	cyclone and the post-cyclone–90.1%	Croakers	0	10.2	8.04	8.93
		Indian mackerel	0	10.1	7.97	8.85
		Scads	0	8.86	6.99	7.76
		Rock cods	1.52	9.75	6.5	7.21
		Other carangids	0	7.14	5.63	6.25
		Threadfin breams	6.6	0	5.21	5.78
	pre-cyclone and the post-cyclone–67.18%	Oil sardine	46.78	0	10.12	15.06
		Miscellaneous	28.48	1.45	5.84	8.7
		Indian mackerel	35.04	10.1	5.39	8.03
		Threadfin breams	23.59	0	5.1	7.59
		Wolf herring	19.02	0	4.11	6.12
		Squids	18.65	0	4.03	6
OBGN	pre-cyclone and cyclone -80.03%	Oil sardine	11.12	0	7.67	9.59
		Big-jawed jumper	10.04	0	6.93	8.66
		Indian mackerel	11.63	1.61	6.91	8.64
		Ribbon fishes	8.63	0	5.95	7.44
		Lesser sardines	8.34	1.76	4.54	5.67
	cyclone and the post-cyclone -45.18%	*E. affinis*	0	3.46	7.39	16.35
		Leather-jackets	0.32	2.41	4.46	9.87
		Other clupeids	0	1.67	3.57	7.9
		Half beaks and full beaks	1	2.3	2.78	6.15
		Scads	0.89	2.05	2.46	5.45
	pre-cyclone and the post-cyclone–67.77%	Oil sardine	11.12	0.89	6.36	9.39
		Big-jawed jumper	10.04	0	6.25	9.22
		Indian mackerel	11.63	1.97	6.01	8.86
		Ribbon fishes	8.63	0	5.37	7.92
		Crabs	7.05	0.63	3.99	5.89
OBHL	pre-cyclone and cyclone–64.75%	*S. guttatus*	7.22	0	10.21	15.77
		Pigface breams	8.17	2.59	7.9	12.2
		S. commersoni	5.89	0.71	7.33	11.33
		Rays	3.63	0	5.14	7.94
		Cuttlefish	3.54	0.32	4.56	7.04
	cyclone and the post-cyclone–49.45%	Miscellaneous	0.55	4.32	8.41	17.01
		Pigface breams	2.59	5.96	7.51	15.18
		Half beaks andfull beaks	0	2.41	5.36	10.85
		Snappers	2.05	4.23	4.86	9.83
	pre-cyclone and the post-cyclone–48.31%	*S. guttatus*	7.22	0	7.96	16.48
		S. commersoni	5.89	0	6.5	13.45
		Rays	3.63	0	4.01	8.3
		Other carangids	3.71	0.55	3.49	7.23
		Miscellaneous	1.22	4.32	3.42	7.08

(MDTN: multiday trawlnet, OBGN: outboard gillnet, OBHL: outboard hook and line) the percentage dissimilarity between the pre and post-cyclone periods was 48.31%. *S. guttatus* and ray landings were not observed during the cyclone period. Also, a low catch of pigface breams, *S. commersoni* and cuttlefish was noted in the cyclone period. In the post-cyclone period, the catch of pigface breams and snappers increased along the Kanyakumari coast (Fig.13 and Table 10).

During the cyclone period, fish resources that formed a major component of the zone were in low abundance on the Kerala and Tamil Nadu coasts. The fish resources were low in all gears, including mechanized, motorized, and non-motorized vessels. In outboard gillnets, pelagic resources such as oil sardine and Indian mackerel were low during the cyclone period. Their catch showed a recovery in the post-cyclone period. This could be due to avoidance of the area by these teleosts, which started appearing in the fishery after the cyclone when the conditions started becoming normal. Also, it might be due to the reduced fishing pressure during the cyclone period (Smee *et al.*, 2020).

Large pelagic fishes such as *Auxis* spp., *K. pelamis* and *S. commersoni* were low in cyclone months in hook and line. Large pelagic fishes such as tuna, seer fish, and carangids are fast-moving fishes. So, the unfavourable conditions in the coastal waters might lead them to avoid these regions. Another difference was the lack of shark landings in the cyclone period and their abundance in the post-cyclone periods. Hydrostatic pressure variations have been known to affect marine animals such as elasmobranchs and sea snakes (Liu *et al.*, 2010; Udyawer *et al.*, 2013). The movement of juvenile blacktip sharks (*Carcharhinus limbatus*) was found to be affected by the drop in barometric pressure associated with tropical storms, and these sharks moved to deeper waters with the approach of the storm. They returned after the storm passage (Heupel *et al.*, 2003).

Near-shore areas where NM crafts were operated showed a reduction in fish catches, such as *Stolephorus* spp. and silver bellies, during the cyclone period. One main change observed was the increased catch of bivalves at Thiruvananthapuram in the non-motorized sector. The Vizhinjam Bay and the rocky zone in Thiruvananthapuram have long supported a good mussel fishery (Ramachandran *et al.*, 1998) and the fishers who were affected by Ockhi would have considered it safer to fish in the near-shore areas, which would lead to their higher catch.

The planktivorous fishes such as oil sardines, lesser sardines, Indian mackerel and *Stolephorus* spp. were low during cyclone Ockhi in the mechanized and outboard ring seines along the Kerala coast. Their catch increased in the post-cyclone months, but that was not high compared to the pre-cyclone months. The increase in fishing efforts and the hike in chlorophyll-*a* concentration after the cyclone may be the reasons for the recovery of the fishery (Giri *et al.*, 2016).

The low abundance of fish such as scads, croakers, and penaeid shrimps was found to be the main change in resource assemblage in the trawl nets, and these started appearing again during the post-cyclone period. Bacheler *et al.* (2019) found that hurricanes influence the movement rates of demersal oceanic fish species. A study on grey triggerfish (*Balistes capriscus*) in North Carolina, USA, found that their movement and emigration rates were much higher during the passage of hurricanes (Bacheler *et al.*, 2019). In Kollam, penaeid and non-penaeid shrimp landings increased in MDTN gear in post-cyclonic months compared to pre-cyclonic time, indicating that the resources in the area had increased. Positive LTA values were observed on the Kerala coast after the cyclone. Coastal upwelling creates low oxygen conditions that would be the reason for the higher catch of shrimps after the cyclone (Prasannakumar *et al.*, 2018).

The low availability of fish during the cyclone started recovering after the cyclone period. The major environmental variations noticed during Ockhi were the lowering of SST, increase in chlorophyll, rainfall, and salinity. Also, variations in LTA and surface currents were noted on all coasts. Declined SST and a chlorophyll hike were favourable for the fishery in the post-cyclone months. Also, positive LTA is favourable for fishing up to a lag of 2 months. The changes in the current direction may have also resulted in the variation in fish abundance.

Hence, the study revealed that changes in marine fish distribution and abundance during cyclones are not long-lasting. The beneficial ecological changes in the habitats following the passage of a cyclone were helpful for higher fish catches in the post-cyclone period.

Conclusion

Tropical cyclones destroy marine ecosystems and affect the coastal fishery. This study found a high species dissimilarity in all selected districts during the cyclone month, and it recuperated in the post-cyclonic months. The environmental variables also showed a similar trend, and these variables correlated with the district-wise total catch. The marine fishery resource landings increased in the post-cyclone period, which may be due to favourable environmental conditions that occurred due to the passage of the cyclone. Targeted research programs to assess the impact of environmental variations during extreme events on eggs, larvae, and juveniles would help to identify the reasons for fishery fluctuations, if any, and assist in fishery predictions.

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