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Effect of *Chattonella marina* [(Subrahmanyan) Hara et Chihara 1982] bloom on the coastal fishery resources along Kerala coast, India

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Chattonella marina, a marine raphidophyte algae which produces haemolytic compounds is capable of damaging fish gills. Blooms of this algae were observed along North Kerala during September 2002, reaching maximum cell density 28×10^{7} cells l^{-1} and in September 2003 with maximum cell density of 135×10^{5} cells l^{-1}. This results in massive fish kills. During the bloom period hypoxic conditions prevailed with dissolved oxygen content ranging between 0.22 and 1.92 mg l^{-1} To assess the impact of the bloom on the coastal fishery resources of the region, the fish landing data of five gears such as outboard trawl net, outboard drift net, outboard gill net, outboard ring seine and country craft gill net were analysed in detail. The landings of fishes which belonged to lower trophic levels decreased. Fishes which were mainly zooplankton feeders like *Stolephorus* spp*, Thryssa* and *Leiognathus* were entirely absent. But there was an increase in catch of the predatory fishes mainly *Euthynnus, Trichiurus, Carcharhinus, Saurida, Scoliodon, Scomberomorus,* and *Sepia* spp which occupy higher trophic level. The variation in catch rate between the bloom and the non-bloom period was significant ($P<0.05$) for *Cynoglossus* spp*, Johnius* spp*, Thryssa* spp *and Parapenaeopsis stylifera* caught in the outboard trawl net. The average taxonomic distinctness (Delta^{+}) was lower during the bloom period and a clear shift in the community structure was observed. The effect of the *C. marina* bloom on fish community was short-lived, and the taxonomic diversity was restored soon after the bloom subsided.

[**Keywords**: *Chattonella marina,* bloom, fishery impact, drift net, ring seine, taxonomic distinctness]

Introduction

Harmful microalgal blooms pose a serious threat to human health, coastal activities, and fishery resources throughout the world. A normal diatom dominated bloom is usually considered favourable for the fishery production of the region whereas harmful blooms are unfavourable as the fishes tend to avoid such areas of bloom either due to the heavy biomass or due to the production of toxic substances which are harmful to it. Raphidophytes have been identified to produce neurotoxic, haemolytic and haemoagglutinating compounds as well as superoxide and hydroxyl radicals which cause severe damage to fish gills leading to osmoregulatory problems and mortality[1-3]. *Chattonella antiqua* and *Chattonella marina* are the major cause of fish mortality in aquaculture farms in Japan.

C. marina first described by Subrahmanyan[4] from a bloom along the Calicut coast of North Kerala has been associated with fish and faunal mortality and fish avoidance along the Indian coast since the early period of the last century[5-7]. The near-shore regions of Calicut coast, constitute a region where *Chattonella marina* blooms persists for a consistently longer period than in other regions. Change in the ecosystem level are bound to affect the fishery resources of the region as well, which will be reflected in the catches landed in the region. For such studies taxonomic measures are used. A more far reaching change, representative of what is happing to the community as a whole, is indicated by looking at the taxonomic relatedness statistics based only on presence /absence data [8] .An investigation of the taxonomic structure of demersal fish assemblages in North Sea, English Channel and Irisih Sea motivated by the concerns over impacts of beam trawling is reported[9]. Similarly taxonomic distinctiveness has been applied for demersal fish[10], for star fish and brittle stars of polar regions[11] and for Atlantic starfish assemblages[12]. To assess the impact of the bloom on the coastal fishery resources of the region, the fish landing data of north Kerala region during the bloom and immediate non bloom period was analysed in detail and was related to the harmful algal bloom.

Materials and Methods

A study on occurrence and the blooming of *Chattonella marina* and its effect on the fishery was conducted along the Kerala coast from October 2001 to September 2003. The bloom and non bloom period were identified based on the phytoplankton cell densities. A particular phytoplankton species assemblage was considered to be in bloom condition when its cell densities increased at least ten times that of the normal. The period October 2001 to March 2002 did not have any major blooms, hence was not considered for comparisons.

Plankton analysis

Sampling was carried out on a monthly basis for a period of two years from October 2001 to 2003, at Chombala, a fishing village along the north Kerala coast. During the period of bloom the sampling frequency was increased and sampling was done on the 1st, 8th and 22nd day till the bloom subsided as indicated by the complete absence of the species from the bloom region. More sampling sites such as Konadu and Kappad villages (Fig 1) were added when the bloom area spread.

Phytoplankton water samples were collected using a phytoplankton net of mesh size 30 μ, mouth diameter 50 cm and with a total length of one meter. The net was hauled horizontally for 15 minutes from a boat. After hauling, the phytoplankton sample collected in the bucket at the end of the net was poured into a container and was immediately preserved with 4% formaldehyde for further analysis in the lab. Quantitative estimation of phytoplankton was done by sedimentation method. One ml of the phytoplankton in the sedimented sample was counted using a Sedgewick rafter cell counter. Enumeration was done in triplicates and the average count of phytoplankton expressed in cells l^{-1}. The identification of species into different taxonomic categories was based on the standards keys[13-16]. Dissolved oxygen of the samples was estimated based on Strickland and Parsons[17].

Impact on fishery

The fishery data collected by the Fishery Resource and Assessment Division (FRAD) of Central Marine Fisheries Research Center (CMFRI) was utilized for assessing the effect of *Chattonella marina* bloom. The fishery landings are estimated by the Stratified multistage random sampling method[18]. For this study, the landing data by the different gears operating in the Calicut coast (Lat 11° 43′ N, Long 75° 33′ E) classified as the K-8 B zone was collected, since the areas with regular bloom occurrences come under this zone. The macro-level changes observed in the preliminary database, were used to trace the micro-level species specific variations. The following inputs were used to identify the main marine commercial fishery species which are affected by the blooming of *C. marina.*

The catch from the fishing crafts operating in the K-8 B zone of Calicut region, are landed in the two major harbours namely Chombala fishing site and Puthiyappa and in the 3 major landing centers and 11 minor landing centers(Fig. 2). The landing from all these sites using gears viz. outboard trawl net (hand

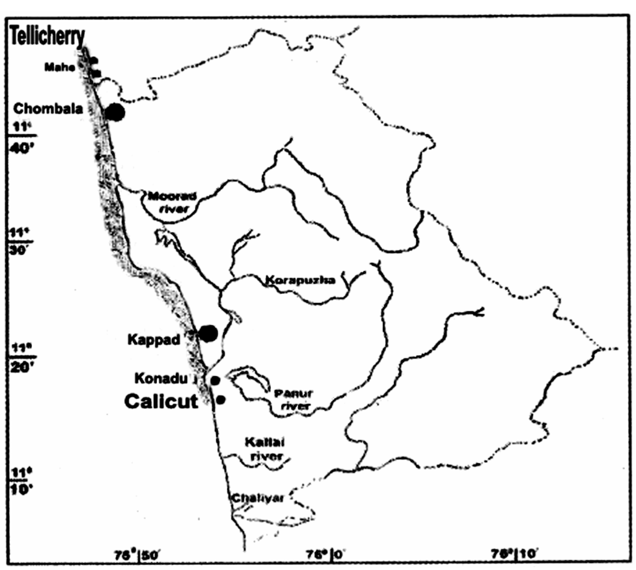


Fig. 1 — Map showing the bloom area from Calicut to Tellicherry –Shaded regions indicate the extent of the bloom sampling sites

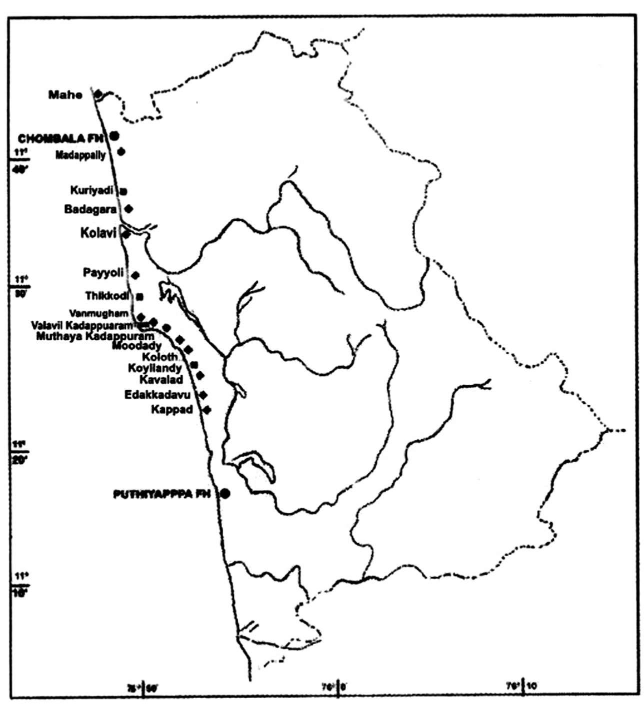


Fig. 2 — Map showing the main landing centers in K-8 B zone.

trawl) (OBTN), outboard drift net (OBDN), outboard ring seine (OBRS), outboard gill net (OBGN), and country craft gill net(CCGN) were used for the study. These gears generally operate within a distance of 55 km from the shore.

The variation in magnitude of total monthly landings during the period between October 2001 and December 2003 was used for assessing the impact of the bloom. The bloom during September 2002 when the alga bloomed at a density of 28×10^{7} cells l^{-1} was taken as Bloom I and the bloom in September 2003 when it reached a bloom density of 17×10^{4} cells l^{-1} was taken as Bloom II. To investigate the effect of the bloom on the marine resource, the catch per unit effort per day (CPUE) for these species during the immediate pre-bloom and post-bloom period was compared with that of bloom period. Thus a micro-level analysis which was restricted to 6 months was carried out as described below. May, July (excluding the trawl ban period) and August were considered as pre-bloom period since in June and July the fishery was low due to the unfavourable weather conditions. Moreover the trawl ban enforced by the government of Kerala was also in prevalent during this period. October and November were considered as post-bloom period when *Chattonella marina* was not present at the site and also when there was no bloom of any other species.

Micro-level analysis to study the impact was done by the following method.

The landings for each gear for each landing center in the K-8 B zone was collected from FRAD and this was pooled to estimate the monthly landing by a particular gear for the zone. The monthly species wise landing of each gear from each landing center was also estimated using this data and the landings from all the centers were pooled to obtain the total species wise monthly landings by a particular gear for the zone. The data from all the gears for each month was pooled to obtain the total monthly landing for the zone. The catch estimates pertaining to 66 genera of finfishes (33 pelagic and 33 demersal), 13 crustaceans and 4 cephalopods were collected by the FRA Division for the region. The total and gearwise monthly catch was estimated for each species and grouped into pelagic and demersal finfishes, crustaceans and molluscs. The magnitude of variation of catch for each group was critically analyzed and micro-level tracing within each group was done. Only those species whose landings showed variation during the bloom period were selected for further analysis. To analyse the impact on species affected by the bloom, the fishery at Chombala fishing site was studied in particular and micro-level analysis was done with reference to catch from gears operated from this region. Microlevel analysis of the species which were found to be affected as indicated by the monthly landing was done by critically analyzing the variation in catch per unit per day between the bloom and the non-bloom period. Here, the catch of a particular species in a specific gear was considered. Data was not pooled to avoid the error due to variation in efficiency of the gear. The species which were subjected to this analysis were *Cynoglossus* sp, *Johnius* sp, *Thryssa* spp, *Parapenaeopsis stylifera, Metapenaeus dobsoni, Penaeus indicus* and *Leiognathus* in outboard trawl net, *Euthynnus* and *Scomberomorus commersoni* in ouboard drift net and *Sardinella longiceps* in outboard ring seine. For assessing the significance of variation of CPUE of species subjected to microlevel analysis, one-way ANOVA was done using the SPSS 7.5 software and for those species which showed significant variation between these study periods, post hoc Duncan's test was done.

Effect on Community Structure: Taxonomic Diversity Indices

Species richness is heavily dependent on sampling effort, which is highly variable in this case and since only the weight of the fishes landed were obtained and not the numbers, the taxonomic diversity index, viz. average taxonomic distinctness was calculated[19].

Taxonomic diversity indices are a type of diversity indices which are based on relatedness of the species within the sample. They were based on the assumption that a sample containing species belonging to distantly related species is more diverse than a sample containing closely related species. This is usually defined from a Linnaean classification and requires an aggregation file in addition to the data worksheet. The aggregation file is used as a look up table which gives the taxonomic relationship and the distance apart of any two species in the sample. The taxonomic tree constructed consisted of 7 taxonomic levels starting from the genus level and extending to family, suborder, order, class upto the level of phylum. All branch lengths were assigned equal weights.

Average Taxonomic Distinctness (Av TD)

Average taxonomic distinctness is defined as the average path length between any two randomly chosen species present in the sample. This measure uses the presence/absence data of the species in the sample and is calculated according to Clarke and Warwick (1998) as

$$\text{Delta}^{+} = \frac{[\Sigma\Sigma_{i<j}\omega_{ij}]}{[S(S-1)/2]}$$

where S is the observed number of species in the sample, and the double summation ranges over all pairs i and j of these species($i<j$).

Expected Distinctness Tests and Funnel Plots

When the data are reduced simply to presence/ absence, not only distinctness, Delta^{+} can be compared across samples of different size but a significance test can also be carried out which tests for departure of Delta_m^{+}, the distinctness measure for any sample of m species, from the overall value Delta^{+} obtained from an aggregation species list for that region. The test is based on the assumption that the average taxonomic distinctness of a randomly selected sublist does not differ in mean value from the average taxonomic distinctness of a master list. This tests for departure Delta_m^{+}, the distinctness measure of any sample of m species from a global species list for that region. The test is based on the theoretical mean and variance of Delta_m^{+} values obtained by random sampling of m species from the total list of s species[19]. Although the theoretical mean remains constant, the variance naturally increased as m decreases and so the approximate 95% confidence interval takes the form of a funnel. The values of Delta^{+} for any particular set of samples can then be related to this confidence funnel to find the extent to which their taxonomic distinctness falls significantly below or above the expected distinctness. Assuming a null hypothesis that each sample is a random selection from the total species list, all values of Delta^{+} should fall within the confidence funnel. A whole taxonomy list prepared from all the fishes, crustaceans and molluscs present in the landings of the region during the study period which was classified based on Linnaean system of classification was used for the construction of the master species list. The fishes, crustaceans and cephalopods were identified based on standard keys[20-23].

Results

In the north Kerala region the harmful alga *Chattonella marina* was present in the phytoplankton community only during September 2002 and September 2003. A widespread and high density bloom of *Chattonella marina* occurred in the first week of September 2002. The bloom showed a discontinuous distribution and extended over a distance of about 50 kilometers along the coast, from Konadu near Calicut to Mahe near Tellicherry (Fig. 1). The distribution was ascertained by estimating the plankton densities at various points along the coast within this region. The muddy green coloured bloom was very noticeable at Kappad, where it extended from the shoreline to about a distance of about 3 kilometers towards the sea. It was visible as streaks and patches in other areas.

Phytoplankton characteristics of the harmful algal bloom

Phytoplankton analysis in the bloom region showed a high density of *C. marina,* $28{\times}10^{7}$ cells l^{-1} at Kappad on the first day of the bloom. Other phytoplankton were few, but present in high densities and included *Coscinodiscus asteromphalus* at a density of $8{\times}10^{4}$ cells l^{-1}, *Pleurosigma normanii* at $2{\times}10^{4}$ cells l^{-1} and *Noctiluca sigma* at a density of $4{\times}10^{4}$ cells l^{-1}. By the eighth day, density of *C. marina* had decreased considerably to 4234 cells l^{-1}. *C.asteromphalus* (1312 cells l^{-1}), *P.normani* (22 cells l^{-1}) and *N. sigma* (552 cells l^{-1}) were the other species of phytoplankton present. By the 22nd day, the density of the harmful algae was reduced to 2200 cells l^{-1}. The density of *C.asteromphalus* had increased to 38,400 cells l^{-1}, *P.normanii* to 164 cells l^{-1} and *Noctiluca sigma* to 235 cells l^{-1}.

At Konadu, the density of *C. marina* was very low when compared to that of Kappad. On the first day *C.marina* was present at a density of 40,000 cells l^{-1} along with the diatom *C.asteromphalus* at a density of 8100 cells l^{-1} and *N.sigma* at 120 cells l^{-1}. By the eighth day the density of harmful algae had decreased sharply to 2815 cells l^{-1} while the diatom *C.asteromphalus* increased to a density of 13,200 cells l^{-1}. *P. normani* at a density of 1350 cells l^{-1} and *N.sigma* at 5500 cells l^{-1} were the other diatoms present. On the 22nd day *C. marina* was present at very low densities of 480 cells l^{-1}. The density of *C.asteromphalus* had increased to 45600 cells l^{-1}, *P.normani* to 1730 cells l^{-1} and *N.sigma* to 12,500 cells l^{-1}.

C. marina was not present at Chombala fishing site during the first week. By the second week *C.marina* bloom was noticed at this site and phytoplankton analysis showed that it was present at a high density of $1.7{\times}10^{4}$ cells l^{-1}. The harmful alga *Noctiluca* *scintillans* was also detected at a density of 100 cells l^{-1}. *C.asteromphalus* at a density of 24700 cells l^{-1}, *P.normani* at a density of 2300 cells l^{-1} and *N.sigma* at a density of 8100 cells l^{-1} were the other algae present. Sampling on the 14th day showed that the concentration of the harmful algae had decreased to 2990 cells l^{-1}, *N.scintillans* to 60 cells l^{-1} and that of *C.asteromphalus* to 2800 cellsl^{-1} at the site. *P. normanii* and *N. sigma* were also present in the sample, but at very low densities. In September 2003 the bloom was severe with maximum cell density of 135×10^5 cells l^{-1} but was for a short period of 5 days.

A very low dissolved oxygen value of 0.22 mg l^{-1} was recorded on the 1st day at Kappad which slightly increased to 1.66 and 1.86 mg l^{-1} on the 8th and 22nd day. The dissolved oxygen content at Chombala fishing site fishing site during the bloom period was low, of 1.92 mg l^{-1} which increased to 3.52 mg l^{-1} on the 22nd day.

Effect on Fishery

The catch estimates pertaining to 66 genera of finfishes (33 pelagic and 33 demersal), 13 crustaceans and 4 cephalopods were collected by the FRA Division for the region. The crustaceans were composed of mantis shrimps, crabs and lobsters while squids, cuttlefishes and octopuses formed the molluscan component. A general impact grading of species was done based on the presence/absence of the species and the variation in the magnitude of the monthly landing. Accordingly, the species were graded into four categories.

1) Species present only during the bloom.
2) Species present in the catch throughout the year, except during the bloom period.
3) Species present in the catch throughout the year including the bloom period, but whose magnitude of landings decreased during the bloom period compared to the non-bloom period.
4) Species which were present in the catch throughout the year including the bloom period, but whose magnitude of landings increased during the bloom period over that of the non-bloom period.

The general impact on fishery observed was mass mortality of fishes and bivalves in the region between Puthiyappa and Kappad. Fishes were killed and were washed ashore all along the shore between these two stations. The fishes which suffered mortality due to the bloom were mostly demersal. Eels formed a major percentage of the dead fish followed by sciaenids and croakers. Major fishes which were killed included *Epinephelus* sp*, Otolithes* sp*, Cynoglossus* sp and *Johnius* sp.

The fish and bivalve samples analysed at Central Institute of Fisheries Technology did not show any toxin in the meat. The fishery of the region faced a serious set back due to the red tide. The major species which were affected by the bloom, and their variation in the fishery landings is represented in detail in Table 1.

i) Species which appeared in the fishery only during the bloom

In the fishery of north Kerala some fish species were noted only during the month of the bloom, when *C.marina* was present at high cell densities in the region and the months just preceding and succeeding the bloom. This included the pelagic fishes *Albula vulpes, Auxis* sp*, Istiophorus* sp*, Trichiurus* sp and the demersal fishes *Arius* sp*, Pristipomoides* sp*, Scoliodon* sp*, Echeneis* sp and the ray *Himantura* sp. Among these, *Auxis* sp*, Istiophorus* sp*, Himantura* sp, occurred again in the fishery during the bloom II.

ii) Species which were absent in the fishery only during the bloom period

The clupeid *Stolephorus* sp and the crustaceans *Portunus pelagicus, Portunus sanguinolentus* and *Parapenaeopsis stylifera* which were present throughout in the landings from the region were absent during Bloom I. During Bloom II, the fishes *Stolephorus* sp*, Leiognathus* sp and the crustaceans *Metapenaeus dobsoni, Parapenaeopsis stylifera, Portunus sanguinolentus* were absent in the fishery landings.

iii) Species whose catch decreased during the bloom period

The groups whose landings showed a general decreasing trend were mainly the carangids and the crustaceans. The landings of *Caranx* sp*, Thryssa* sp*, Johnius* sp*, Megalaspis cordyla*, *Leiognathus* sp and the shrimp *Penaeus indicus.* Besides these, the benthic fish *Cynoglossus* sp*,* also showed a reduction in total landings during the bloom period. During bloom II a reduction in landings of almost the same species were observed. The landings of the carangids, *Johnius* sp*, Megalaspis cordyla* and *Thryssa* sp decreased during the bloom. *Caranx* sp was less in the pre and post-bloom period but was slightly higher in the bloom month of September. The landings of *Penaeus indicus* and *Cynoglossus* also decreased during the bloom.

Table 1 — Effect *of Chattonella marina* bloom on the commercial fishery species and marine fauna

Species	Behaviour/Reaction to *Chattonella marina*	Effect on fishery	Possible reasons	Remarks
Sardinella sp, *Rastrelliger* sp	Avoidance	Increase in gears operating away from the shore	Stressed environment, exclusion of favourable phytoplankton food	Sensitive
Euthynnus sp, *Sarda orientalis*, *Auxis thazard* *Carcharhinus melanopterus, Scoliodon* sp *Scomberomorus* sp, *Sphyraena* sp, *Istiophorus* sp, *Trichiurus* sp, *Chirocentrus* sp *Sepia* sp	No direct effect	Increase in CPUE	Increased availability of prey	Aggregation/ migration to near shore non-bloom areas
Epinephelus sp, *Himantura* sp *Cynoglossus* sp	Large scale mortality	Appearance in non targeted gears	Avoidance of the bloom area due to the stressed environ.	–
Stolephorus sp, *Caranx* sp, *Thryssa* sp, *Leiognathus* sp, *Megalaspis cordyla M. dobsoni*, *P. indicus*, *Portunus pelagicus*, *P. sanguinolentis*, *Parapenaeopsis stylifera, P. monodon.*	Decreased presence in the region	Decrease in CPUE	Low phytoplankton and zooplankton biomass	Sensitive
Opisthopterus sp, *Esculosa* sp, *Dussumieria* sp, *Anodontostoma* sp, *Chorinemus*, *Lactarius*, *Coryphaena* sp, *Decapterus* sp, *Pristipomoides* sp, *Pellona ditchela*, *Hemirhamphus*, *Rachycentron canadus*, *Otolithes* sp, *Therapon, Ambassis* sp, *Sillago, Strongylura*, *Scatophagus* sp, *Polynemus* sp *Gerres* sp, *Formioniger* sp, *P. argenteus*, *Johniops*, *Lutjanus* sp, *Mene maculata*	No visible effect observed	No quantifiable change in fishery observed.	Mostly pelagic, capable of moving away from stressed environ.	Sensitive
Albula vulpes, *Echeneis*	Occurred only during the bloom period	-	Disturbance in the habitat, toxins, low diss.oxygen levels	Highly sensitive
Arius sp	Disorientation/ Erratic swimming behaviour	Increase in CPUE	Disturbance in the habitat, toxins, low diss. oxygen evels	Highly sensitive
Muraenesox sp	Asphyxiation, large scale mortality	-	”	Highly sensitive
Perna viridis, *Mactra* sp, *Donax* sp *Emerita* sp	Large scale mortality	Fishery temporarily closed	Sedentary nature and continued exposure to HAB	Sensitive

iv)) Species whose catch increased during the bloom period

The species which showed increased numbers in the catch during the bloom, were *Sphyraena* sp, *Saurida* sp, *Priacanthus* sp, *Euthynnus* sp and *Epinephelus* sp and the cephalopod *Sepia* sp. The catch of *Euthynnus* which increased during the Bloom I also showed an increase in the landings of Bloom II.

Gear wise variations in fishery

Significant variations in landings were observed in outboard trawl net (OBTN), outboard drift net (OBDN), outboard ring seine (OBRS) the results of which are given in detail below.

Outboard Trawl Net (OBTN)

The OBTN (hand trawl) operates very close to the shore at a distance ranging between 1 to 15 km and at a depth between 3 and 24 m. The variation in catch rate of *Cynoglossus* spp, *Johnius* spp, *Thryssa* spp, *P.stylifera, M.dobsoni, P.indicus and Leiognathus* spp in outboard trawl net operated in the coastal waters of Chombala were analysed. The average catch during the months of analysis for Bloom I along with the results of the ANOVA and Duncans post-hoc tests are given in Table 2. Of these, the variation in catch rate between the bloom and the non-bloom period was

Table 2 — Average catch per unit effort (kg) of major fish species which showed variations in the landings of outboard trawl net during the bloom period in September ’02 and ‘03. Results of ANOVA-post hoc Dunchans Test are shown as superscipts. Non-identical superscripts (row wise) indicate months with significant differences (P<0.05).

Species	F value	P	Average catch per unit (kg)					
			Pre-bloom I		Bloom I		Post- bloom II	
			May	Jul	Aug	Sept	Oct	Nov
Cynoglossus sp	22.58	0.000	20.9^{a}	9.4^{b}	0^{b}	0.7^{b}	52.5^{c}	38.2^{c}
Johnius sp	7.991	0.001	4.48^{b}	4.35^{b}	2.95^{b}	0.33^{a}	4.47^{b}	4.67^{b}
Thryssa sp	5.267	0.009	6.17^{a}	3.9^{b}	1.38^{b}	1.17^{b}	7.07^{a}	6.33^{a}
P. stylifera	7.244	0.029	6.37^{b}	2.8^{a}	0^{a}	0.1^{a}	3.1^{ab}	5.49^{ab}
M.dobsoni	0.562	0.693	1.17^{a}	1.5^{a}	0.97^{a}	2.07^{a}	1.18^{a}	1.369^{a}
P.indicus	1.369	0.298	^{a}	1.57^{a}	0.783^{a}	0.15^{a}	0.083^{a}	0.143^{a}
Leiognathus sp	1.081	0.404	^{a}	13.45^{a}	0.42^{a}	14.37^{a}	6.3^{a}	^{a}
			Pre-bloom II		Bloom II		Post- bloom III	
			May	July	Aug	Sept	Oct	Nov
Cynoglossus sp	21.52	0.000	3.4^{b}	3.2^{b}	4^{b}	5.8^{b}	63.8^{c}	12.6^{c}
Johnius sp	3.998	0.031	1.3^{ab}	6^{c}	3.9^{bc}	4.7^{bc}	2.3^{abc}	3.8^{abc}
P .indicus	1.219	0.357	2.37^{a}	0.77^{a}	1.16^{a}	2.76^{a}	^{a}	^{a}

significant (P<0.05) for *Cynoglossus* spp, *Johnius* spp, *Thryssa* spp *and P.stylifera.*

Catch of carangids *Johnius* spp *and Thryssa* spp showed significant variation (P<0.05) between the bloom and the non-bloom period. The average catch per unit of *Johnius* spp showed a decrease in September (0.33 kg) when the harmful microalgae *C.marina* bloomed. In the case of *Thryssa* spp, the catch per unit was lower in the bloom month of September (1.17 kg) and in the preceding months July (3.9 kg) and August (1.38 kg) also.

The ANOVA results showed that the variation in landing was highly significant for the benthic fish *Cynoglossus* spp (P<0.05). The average catch per unit was low from July to September and increased immediately in October following the bloom. It was higher and similar in May and November than the bloom months. The catch rate of the shrimp *Parapenaeopsis stylifera* also showed significant differences (P<0.05) between the bloom and the non-bloom months. The average catch per unit effort showed a decreasing pattern with the bloom with the highest in pre- bloom month of May and decreasing to nil landings in the bloom period from August to September and thereafter increasing again. Beside the above species, the CPUE of *M.dobsoni, Penaeus indicus* and *Leiognathus* showed a variation during the bloom period. The differences were however not significant (P>0.05).

During Bloom II catch per unit effort showed significant variation for *Cynoglossus* spp (P<0.05) while it was not significant for *Johnius* spp and *P.indicus*. The average catch during the months of analysis for Bloom II along with the results of the ANOVA and DMRT are given in Table 2

Outboard Drift Nets (OBDN)

The OBDN is operated further away from the shore at a distance ranging between 15 and 55 km and at a depth between 35 and 70 m.The average catch per unit of *Euthynnus* sp was comparatively high in the bloom month of September when compared to the pre-bloom and post-bloom months. The catch of *Euthynnus* sp per unit of OBDN between the bloom and the non-bloom months were significantly different (P<0.05). The catch rate of *Scomberomorus commerson* however did not show significant variation between the bloom and the non-bloom period. The average catch during the months of study along with the ANOVA results of the level of significance is given in Table 3.

The catch rate of *Euthynnus* sp in outboard drift net between the bloom and the non-bloom period in Bloom II were also significantly different (Table 3). The level of variance was significant (P<0.05) for the species. The average catch rate was 38.05 kg in the bloom period and 0.17kg in the post-bloom months.

Outboard Ring Seine (OBRS)

The OBRS operates at an average distance ranging between 6 to 50 km from the shore and at a depth between 18 to 50 m. The variation in catch rate of sardines obtained in the outboard ring seine were analysed. The average catch of sardine per unit was highest (2703 kg) in the bloom month of September. There was no significant difference in the average catch rate between the bloom and the non-bloom period (P<0.05).

Outboard Gill Net (OBGN)

The OBGN operates at a distance ranging between 1 to 30 km from the shoreline and at a depth between

Table 3 — Average catch per unit of major fish species which showed variations in the landings of Outboard drift net during the bloom in September '02 and '03. Results of ANOVA - post hoc Dunchans Test are shown as superscipts. Non-identical superscripts (row wise) indicate months with significant differences (P<0.05).

Species	F value	P	Average catch per unit (kg)		
Outboard Drift Net-September- 2002					
			Pre- bloom	Bloom	Post- bloom
Euthynnus *sp*	8.054	0.005	12.37[a]	188.67 [b]	1[a]
Scomberomorus sp	0.499	0.771	23.8[a]	12.92[a]	26.65[a]
P .indicus	1.219	0.357	0.058[a]	2.37[a]	0.77[a]
Outboard Drift Net-September- 2003					
				Bloom	Post bloom
Euthynnus sp	23.69	0.017		38.05 [a]	0.17[b]

2 to 50 m. During bloom I, the catch increased to 68 t. The increased landing in Bloom I was due to the catch of *Trichiurus* sp which was obtained in this gear only during the bloom period in September and October in both years. There was a heavy landing of *Trichiurus* sp, 75.3 t in September 2003, which decreased to 40 t in October 2003. Other species which contributed to the increased landings in September 2003 was *Sphyraena* sp with 32.62 t, *Hemirhamphus* sp at 34.8 t and *Caranx* sp at 51 t. *Belone* sp, a finfish was detected only in the bloom period in October '02 and from October to November 2003. *Istiophorus* was another species which was present only in the pre-bloom month of August 2003.

Country craft Gill Net

The landings from non mechanized gill net was low in the bloom period in both the years when compared to the pre and post-bloom months. *Sardinella* sp was absent in the catch in September '02 but was present in pre and post-bloom months. *Himantura* sp a benthic ray was obtained in the catch in August and September '02 with landing of 3.92 and 0.31 t respectively. *Arius* sp was landed starting from September and was landed upto December 2002.

Effect on Community Structure: Average Taxonomic Distinctness (Delta$^+$)

Average taxonomic distinctness (TD) showed a reduction during the bloom and the post-bloom period in both studied years. The number of genera which contributed to the fishery landings and the average taxonomic distinctness between the monthly species assemblage during the period from October '01 to December '03, is given in Fig. 5. The average taxonomic distinctness (Delta$^+$) value decreased from 73.7 in May '02 to 65.04 in July '02. It increased slightly to 68.6 in the pre-bloom month of August '02

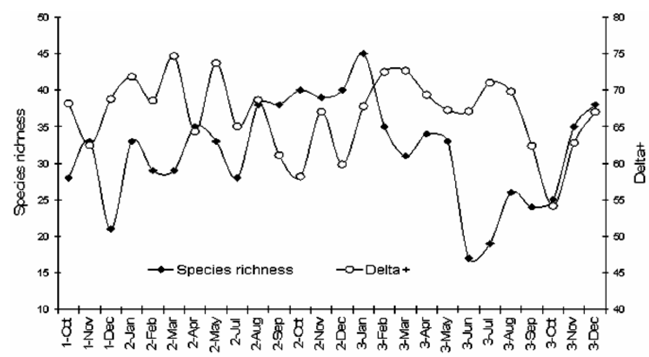


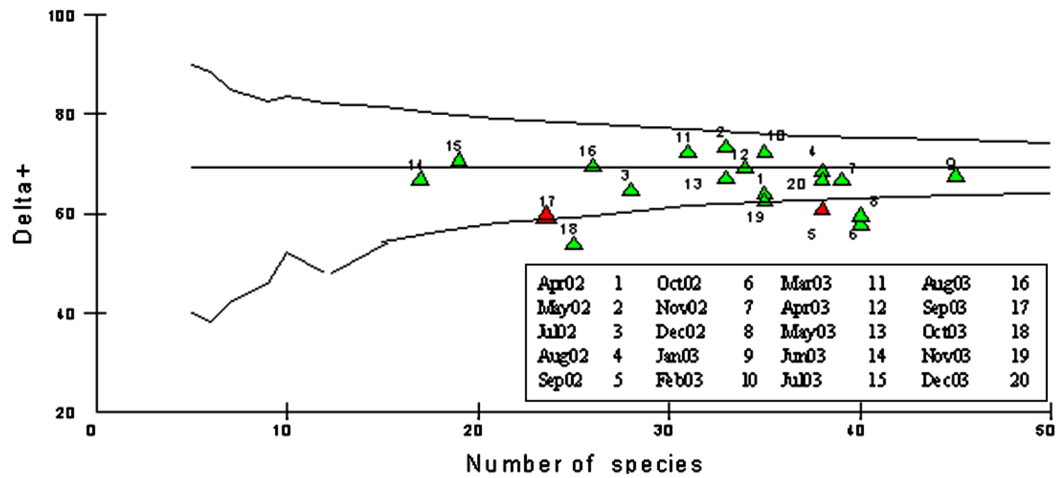
Fig. 3 — Variation in species numbers and taxonomic distance at Calicut during the period from October 01 to December 03

and decreased to 61.09 in the bloom month of September '02 and further to 58.19 in October '02 after which it increased to 67.03. Although taxonomic distinctness was low during the bloom period, the number of genera was not lower indicating a clear shift in the community structure of the region. The number of genera was 38 in August and September and 40 in October.

The Delta$^+$ value decreased during the bloom II also. It decreased from 71 in July to 69.8 in August and to 62.37 during the bloom in September and to the lowest of 54.14 in the post-bloom month of October '03. The species numbers was higher in the bloom period than in the months immediately prior to the bloom but was lower than in the months succeeding it. The variation in species numbers and taxonomic distance during the period from October '01 to December '03 is represented graphically in Fig. 3.

Expected Distinctness Tests-Funnel Plots

Funnel plots were plotted to depict the statistical deviation in taxonomic distinctness during the bloom period from the theoretical mean for the region.



Apr02	1	Oct02	6	Mar03	11	Aug03	16
May02	2	Nov02	7	Apr03	12	Sep03	17
Jul02	3	Dec02	8	May03	13	Oct03	18
Aug02	4	Jan03	9	Jun03	14	Nov03	19
Sep02	5	Feb03	10	Jul03	15	Dec03	20

Fig. 4 — Funnel plot which plots the 95 % confidence intervals for a range of subsamples and the comparison of the average taxonomic distinctness of the samples with the theoretical mean of the region. Central straight line — Theoretical mean; curved line- 95% confidence limits. 17 and 5 are bloom months

Delta$^+$ showed significant variations in the bloom month of September ’02 and more in the post-bloom month of October ’02. It was also significantly different from the theoretical mean in December ’02. During Bloom II the taxonomic distinctness deflected significantly away from the theoretical mean again in the bloom month of September ’03 and in the post-bloom months of October and November, with highly significant deflection in October ’03.

The funnel plot (Fig. 4) compares the average taxonomic distinctness during the months from April ’02 to December ’03. In the funnel plots it can be clearly seen that the bloom months of September ’02 deflected away significantly from the theoretical mean than September ’03. The post-bloom month of October was also found to deflect significantly away from the theoretical mean in both the instances.

Discussion

It is a well-known fact that a substantial phytoplankton biomass leads to a rich zooplankton crop and high survival of young fish, especially the larvae and the juveniles[24,25]. Fluctuations in the phytoplankton crop of the region in relation to environmental factors therefore reflect the variability in the recruitment and survival of edible fish stock of a region. Analysis of the fish landings of the Calicut region indicated that the coastal fishery of the region is affected by the *C. marina* bloom, however this lasted for a short period.

Fish mortality along the Indian coast has been associated with the blooming of the phytoplankton genera *Noctiluca, Trichodesmium* and *Gymnodinium mikimotoi.* The avoidance of the bloom area by fishes along the Calicut coast has been reported as early as 1948[26]. It was observed that the commercially important shoaling species like sardine and mackerel shift from foul water areas to more favourable grounds in the neighbourhood. In these waters this shifting of the fishery has been observed during the excessive production of *Noctiluca*, euglenoids, *Nitzschia* and *Oscillatoria.* The euglenoid was later identified as *C. marina* with similar avoidance of the bloom region of this alga by the fishes[4]. It was observed that the oil sardine and mackerel which were landed in good quantities during the months preceding a bloom of *Trichodesmium* spp declined with the bloom and revived with the subsidence of the bloom[27] whereas trawl operations in the areas of dense bloom along Goa coast showed fish catches similar in size and composition as in non-bloom areas[28]. A dense bloom of *Trichodesmium erythraeum* was found to severely affect the fisheries of the Minicoy island with the fishes completely avoiding the area during the bloom period[29]. Fall in catches along the Karnataka and Goa coasts during the bloom of

Noctiluca due to the avoidance of the bloom area by the fishes has also been reported[30,31]. Massive mortality to the marine benthic fishes along the west coast due to *G. mikimotoi* bloom has been reported[32].

Development of fishing craft and gear, especially mechanization and motorization, has resulted in a drastic change in the fishing activity of Calicut, which used to be seasonal in the earlier times. Even in the past the peak fishing season was the post monsoon season as for other regions along the coast. The presence of a seasonal fishery in the inshore waters of the Calicut coast has been mainly linked to plankton production[33,34]. Considering the landings of the region, the catch from all the gears had decreased during the bloom period in both the years. Bloom I was a prolonged one and resulted in large scale mortality of finfishes and shellfishes. The fishes which were mostly affected included the demersal fishes eels, groupers, sciaenids and croakers. Fishes are reported to be killed by anoxia during exposure to *C. marina* red tides[35,36]. Recently neurotoxins have been isolated from these organisms and it is found that the neurotoxin fraction is more toxic to fishes than the hemolytic and hemoagglutinating fractions however with no effect on their consumers[37]. The toxin analysis at Central Institute of Fisheries Technology was positive only for the water samples but not for any of the fish and faunal samples from the region indicating that the toxin does not accumulate and cause any negative effects. Bloom I had resulted in the cancellation of all inshore fishing operations in the bloom area for almost three weeks with a severe negative impact on the fishing economy of the region. The mechanized trawl net operations were cancelled completely. There was an absence of fish shoals starting from the pre-bloom and extending upto the post-bloom periods. The alga has a benthic cyst in its life cycle and its germination during the pre-bloom month could have altered the water quality as evidenced by the low dissolved oxygen values, high total suspended solids and toxin production which were unfavourable to the fish and several marine fauna. The presence of toxin in the water which was produced by the alga must have also caused the avoidance of the region by fish shoals.

More obvious than the decrease in landings was a change in the community structure with a dominance of the community by fishes belonging to higher trophic levels. This was more obvious from the analysis of Av TD tests. Though the species numbers did not vary between the bloom and the non-bloom period, the taxonomic distinctness decreased indicating a stress and a change in the community structure probably linked to the bloom. Clarke and Warwick[19] who examined 14 species list from a range of impacted and undisturbed UK areas found that the Av TD clearly varied in the impacted areas whereas comparatively pristine locations had Av TD similar to the master species list. According to an impact study of beam trawling in taxonomic structure of demersal fish assemblages in the North sea, English channel and Irish sea, Delta$^+$ index was clearly reduced in some areas due to the stress caused by trawling[38].

The landings of all fishes which belonged to lower trophic levels showed a decrease in catch during the blooming of *C.marina* in September 2002. There was however an increase in the catch of sardines mainly from ring seines may be because of the favourable diatom blooms, especially that of *Coscinodiscus asteromphalus* which occurred preceding the harmful algal bloom. An unusually high landing of sardines was also obtained in October 2003 and this coincided again with a bloom of the same diatom in the region. There was however a decrease in sardine landings from gears like hand and mechanized trawl nets which generally operate very close to the shore. This might be because these fishes must have avoided the bloom region due to the irritant property of this alga and since these gears could not venture in these far off regions for fishing due to their restricted mobility, there was a decrease in the catch rate of these fishes in these gears. The decrease in landings in the gears which operated very near to the shore and the unusual catches of some fishes like sardines in outboard drift net and that of *Epinephelus* sp in outboard ring seines clearly indicate that there was a avoidance of the bloom areas by fishes. Fishes which were mainly zooplankton feeders were entirely absent and these included *Stolephorus* spp, *Thryssa* and *Leiognathus.* Their absence can be attributed either to the absence of their food from the region or to the presence of toxins which might have been transferred through the food web. The planktonic herbivores are able to accumulate algal toxins as well as retain them to a certain degree[39]. This in turn would have resulted in the decrease in catch of the groups which in mainly fed on these zooplankton feeders. This included *Caranx* and *Johnius* spp.

There was an increase in catch of the predatory fishes mainly *Euthynnus, Trichiurus, Carcharhinus, Saurida, Scoliodon, Scomberomorus,* and *Sepia* spp all of which occupy the higher trophic level[40]. These species were present in high levels during the pre or post monsoon period during the Bloom I. Except *Sepia* and *Scoliodon* all the other species were present during Bloom II also. The catch of the sharks *Carcharhinus* and *Scoliodon* which form only a very low percentage of the fishery of the region had also increased to the highest during the bloom period, that of the former in both the blooms and the latter during the first bloom only. They feed mainly on pelagic and shoaling teleosts like sardine, scad, mackerel, squids etc. The catch of these predatory fishes had increased during the first bloom. The catch of sardine was high during the bloom periods but the catch of their predators was high only during the first bloom which indicated that in the first instance they might be in a lethargic condition and so was in a condition in which it could be easily caught due to the algal toxin. It is reported that the neurotoxins of *C. marina* were more toxic than other cytotoxins produced by this species[37] Exposure of fish to *C. marina* red tide water has been found to result in asphyxiation and erratic swimming behaviour in fishes[1].

Cell density also seems to play a major role in deciding the presence of this predator species. In September 02 when there was a long lasting bloom in the region with cell densities reaching as high as 28×10^7 cells/l, the presence of the predatory species was maximum in the pre or post-bloom month, probably a period when the toxin levels induced lethargic conditions. With increase in cell density and surface accumulation of the bloom, total avoidance of the bloom area by these fishes was observed. In the second year the densities were however lower and the bloom lasted only for a short period of two days only. Hence the catch of these species were high in the bloom II in September '03 The catch of all shrimps had decreased during the bloom period. The food of the prawn consists of considerable quantities of phytoplankton elements particularly *Fragilaria, Coscinodiscus, Pleurosigma, Navicula, Cyclotella* etc. on some of which the prawn feeds while the cells sink to the bottom or directly from the bottom. A similar decrease in shrimp fishery has been reported during the bloom of the dinoflagellate *Gyrodinium aureolem* which revived after the dinoflagellates dispersed[41].

The results of the present study indicates that the fishery of the Kerala seems to be affected by the *C. marina* bloom. But the effect of the bloom on macrofauna was short lived increasing immediately after the subsidence of the bloom. According to Gosselin *et al*.[42], the kills of adult fishes are sporadic events with limited impacts on fisheries. The emergence of fish larvae and post larvae at a time when the planktonic food web is contaminated by algal toxin could lead to a significant reduction of early survival and threaten recruitment to local stocks. Hence the effect of the algal toxins on the different trophic levels has to be studied in detail.

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