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An unusual fish impingement event in the cooling water system of a nuclear power plant

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The paper presents an unusual event of fish impingement in the cooling water system of Madras Atomic Power Station during 10th to 22nd July 2008. During this short period 79 species (47 reef-associated and 28 demersal) of fishes were collected from the travelling water screen. Interestingly, 5 species new to Tamil Nadu, 3 species new to east coast of India, 2 species new to Indian coasts, 2 species new to Indian Ocean region and a cryptic species were encountered during this study. Occurrence of such a number of new records in a short period of time from this location indicated the role of some sort of oceanographic process in this event. Results of physico-chemical and biological parameters during the study indicated prevalence of upwelling in the coastal waters which might have played a significant role in shaping this event.

[Keywords: Fish impingement, cooling water, power plant, upwelling]

Introduction

Power plants that use once-through cooling system require a large volume of water for their condenser and auxiliary cooling purposes. Screens of different mesh sizes are placed at various locations of the cooling system to prevent the entry as well as to remove organisms which surpass the initial screens. Very small organisms like phyto- and zooplankton, fish eggs and various larval forms pass through the filter screens and through the entire cooling water system in the process of entrainment. Larger organisms are generally impinged on intake screens, which depend up on the screen mesh size as well as on the size of the organisms. Abundance of fish impinged annually in cooling system may be in the order of millions of individuals[1-2]. Estimation of the extent of fish mortality at a power station's cooling water intake helps in assessing the environmental impacts, particularly the effects on biodiversity of the region[2]. This kind of study on impingement also helps to trace the biodiversity and richness of organisms present in that area.

Fish impingement is a general phenomenon in the cooling water systems of coastal power plants. In order to avoid the impingements, power plants follow certain procedures. Mostly, intake screens with a relatively small mesh size are deployed, which do not allow bigger organisms including fishes without hindering the cooling water flow. However, sometimes the impingement of organisms becomes unusually high due to several reasons like breeding periods, strong water current, tidal actions, feeding of bio-growth by the grazers and predators in the cooling water intake structure etc. Fish impingement at Madras Atomic Power Station (MAPS) cooling water system has been in low key and has never caused any problem for operation and maintenance of the plant. The only incidence of impingement that adversely affected the plant leading to its shutdown was the jelly fish ingress that took place nearly two decades ago[3]. Present paper reports a sudden impingement of marine organisms, mostly fishes in a large quantity, for a period of about two weeks (10th to 22nd July 2008), which has not been observed so far in the cooling water system of MAPS,. This incident was observed during our regular coastal water quality monitoring programme. Thus, the hydrobiological data (temperature, pH, salinity, dissolved oxygen, turbidity, phytoplankton, zooplankton, chlorophyll-a) collected weekly, prior to this event and thereafter, were utilized to find out the cause of the above observation. Apart from the field data collection, satellite data for coastal circulation pattern and chlorophyll-a were also obtained and correlated with the fish impingement event.

Materials and Methods

The Madras Atomic Power Station (MAPS) located at Kalpakkam (12˚ 33' N; 80˚ 11' E) consists of two units of Pressurized Heavy Water Reactor (PHWR), each of 235 MW (e) capacity. It uses seawater as the coolant for the condenser and process cooling water systems. The seawater is drawn at the rate of 35 m^3/sec through a sub-seabed tunnel present

53 m below the seabed. The tunnel is 468 m long and is 3.8 m in diameter. It is connected at the landward end to the pump house through a vertical shaft of 53 m deep and 6 m diameter called forebay. Similarly, the seaward end of the tunnel is connected to a vertical shaft of 48 m and 4.25 m diameter called intake. Seawater enters the intake through 16 windows located radially at the intake, 1 m below the lowest low water spring tide. These windows are fitted with two tire defense screens (320 x 200 cm) with 2.5 x 2.5 cm mesh size to prevent the entry of larger organisms and debris.. The tunnel, intake and forebay shafts support a heavy growth of benthic communities such as mussels, barnacles, oysters, ascidians etc. The high density of these biofouling organisms inside the tunnel/cooling systems could be attributed to continuous supply of oxygen & food and removal of excretory products by the passing seawater providing a conducive environment. In addition, absence of any potential predator inside the cooling system supports a luxuriant growth of the biofouling community. The physical shape of the tunnel is such that it is an isolated system open at both ends. The incoming seawater is treated with chlorine at the point where it enters the intake of the sub-seabed tunnel and a residual level of about 0.5 ppm is maintained at the outfall discharge. Water for cooling purpose is supplied with the help of 12 vertical pumps which are connected to the forebay. At forebay, the water is being filtered further by a traveling water screens (mesh size- 1 x 1 cm) to prevent entry of marine organisms, debris etc. (Figure-1).

Methodology

Fishes were collected daily (10.00 A.M. – 12.00 noon), during the period of impingement (10^{th} to 22^{nd} July 2008), from the traveling water screens of MAPS pump house. Water samples were also collected near the cooling water intake for estimation of hydrographical parameters such as temperature, pH, salinity, dissolved oxygen (DO) and turbidity. A mercury thermometer having ±0.1^{o} C accuracy was used for measurement of water temperature. Winkler's titrimetric method was followed for the estimation of DO. Salinity measurements were carried out by Knudsen's method[4]. pH measurement was carried out by a pH meter (CyberScan PCD 5500) having an accuracy of ±0.05. Turbidity of the water samples was measured by turbidity meter (CyberScan IR TB 100) having ±0.1 NTU accuracy. Qualitative analysis of fishes were carried out using fish identification manuals[5-9]. Qualitative and quantitative estimation of phytoplankton and zooplankton were carried out following standard methods[10-15] to find out correlation, if any, with the impingement event. Satellite data on the chlorophyll-a and coastal circulation pattern were obtained from National Remote Sensing Centre (NRSC), Hyderabad. Data on wind velocity and direction were collected for the period of June-August 2008 and represented in form of wind-rose.

Results

Surface water temperature ranged from 28.4-31.5 with a considerable reduction (~ 2 ^{o}C) during June and July (Figure-2) as compared to that of early summer (April-May). A marginal reduction in salinity and pH was noticed during the month of July as compared to other periods, whereas, no particular trend was observed in case of DO and turbidity (Figure-2). Relatively high concentrations of nitrate, ammonia, phosphate and silicate were observed during July as compared to other months (total data presented for the period of April- September). The Aqua MODIS data on chlorophyll-a concentration for the month of July from 2002-2009 showed that, in the year 2008 the coastal waters of Kalpakkam was relatively more productive (chlorophyll-a values ranging from 2.5-10 mg m^{-3}) as compared to 2007 and 2009 (Figure-3). However, chlorophyll-a concentration of the year 2008 was almost similar to that of the years 2003, 2005 and 2006. The coastal circulation pattern showed interesting phenomena during this study period. It was observed that during May and June the coastal waters of Kalpakkam and the nearby area formed a gyre and recirculated in the same region (Figure-4). However, during July the local gyre was absent and a strong current originated from offshore moved towards the coast. A close observation of the vector diagram also showed that velocity of the coastward approaching current was relatively high during July as compared to May and June.

Qualitative and quantitative aspects of plankton

Phytoplankton density in the coastal waters varied from 0.8-11.1 x 10^{5} cells l^{-1} during June – August 2008. Relatively low density of

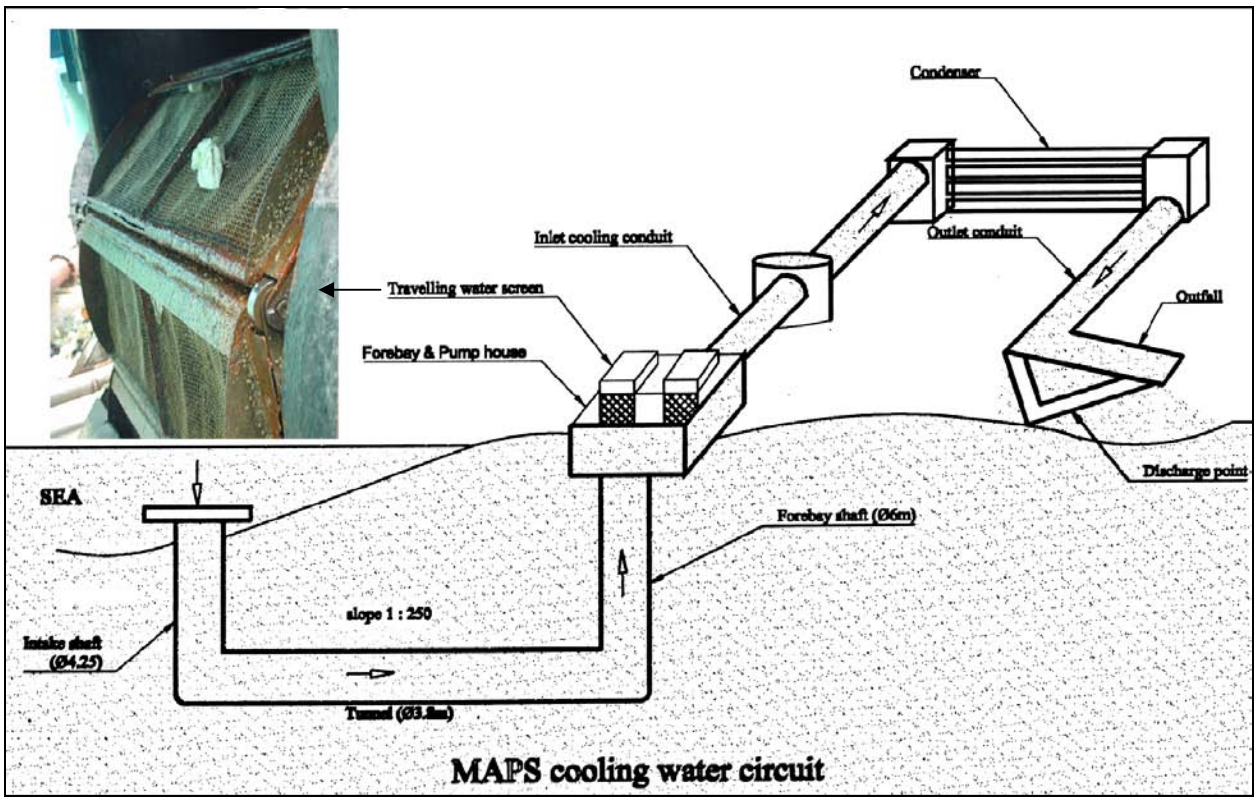

Figure-1: Figure showing the cooling water circuit of Madras Atomic Power Station with the travelling water screen where the fishes were collected

phytoplankton was observed during July as compared to June and August (Figure-5). Zooplankton density also showed a similar variation trend to that of phytoplankton and ranged from 1.3-14.3 x 10^5 organisms $l0m^{-3}$.

In total, 79 fish species belonging to 10 orders, 41 families and 62 genera were identified during the short span of study. All the fishes were members of the phylum Chordata, sub-phylum Vertebrata and mainly divided into cartilaginous (sharks, skates and rays) and bony fish. Of the available 79 species, 47 were reef-associated, 28 demersal, 2 bentho-pelagic and the rest 2 were pelagic-neritic. The occurrence of reef-associated fishes in large numbers indicates the presence of coral and rocky reefs in the nearby areas. A near-threatened species, *Epinephelus coioides*, was also encountered during this study. Interestingly, 5 species (*Torpedo sinuspercisi, Gymnothorax meleagris, Scorpaenodes guamensis*, *Parascolopsis eriomma* and *Canthigaster solandri*) new to Tamil Nadu coast, 3 species (*Enchelynassa canina, Archamia fucata* and *Entomacrodus vermiculatus*) new to east coast of India, 2 species (Brachysomophis cirrocheilos and *Torquigener brevipinnis*) new to Indian coasts, 2 species (Heteroconger tomberua and Opistognathus macrolepis) new to Indian Ocean region and a species (*Scolopsis igcarensis*) entirely new to science were encountered during this study[16-17].

Among the identified anguilliformes, two have been reported to cause ciguatera poisoning while the rest two are supposed to be dangerous to human as their bites are said to be traumatogenic. Species like *Myripristis murdjan*, *Lutjanus fulviflamma* and *Lutjanus rivulatus* are also reported to cause ciguatera poisoning while fishes like *Scorpenodes guamensis*, *Acanthurus xanthopterus, tetrosomus gibbosus* and *Torquigener brevipinnis* are termed as venomous. Fishes from Tetradontidae family like *Arothron hispidus*, *Arothron immaculatus*, *Canthigaster solandri*, *Chelonodon patoca* and *Torquigener brevipinnis* were available in large numbers. The skin and certain internal organs of the fishes from Tetradontidae family are highly toxic to humans due to the presence of tetrodotoxin, a powerful neurotoxin that can cause death in nearly 60% of the humans that ingest it. Some of the species like *Strophidon sathete*, *Plotosus lineatus*,

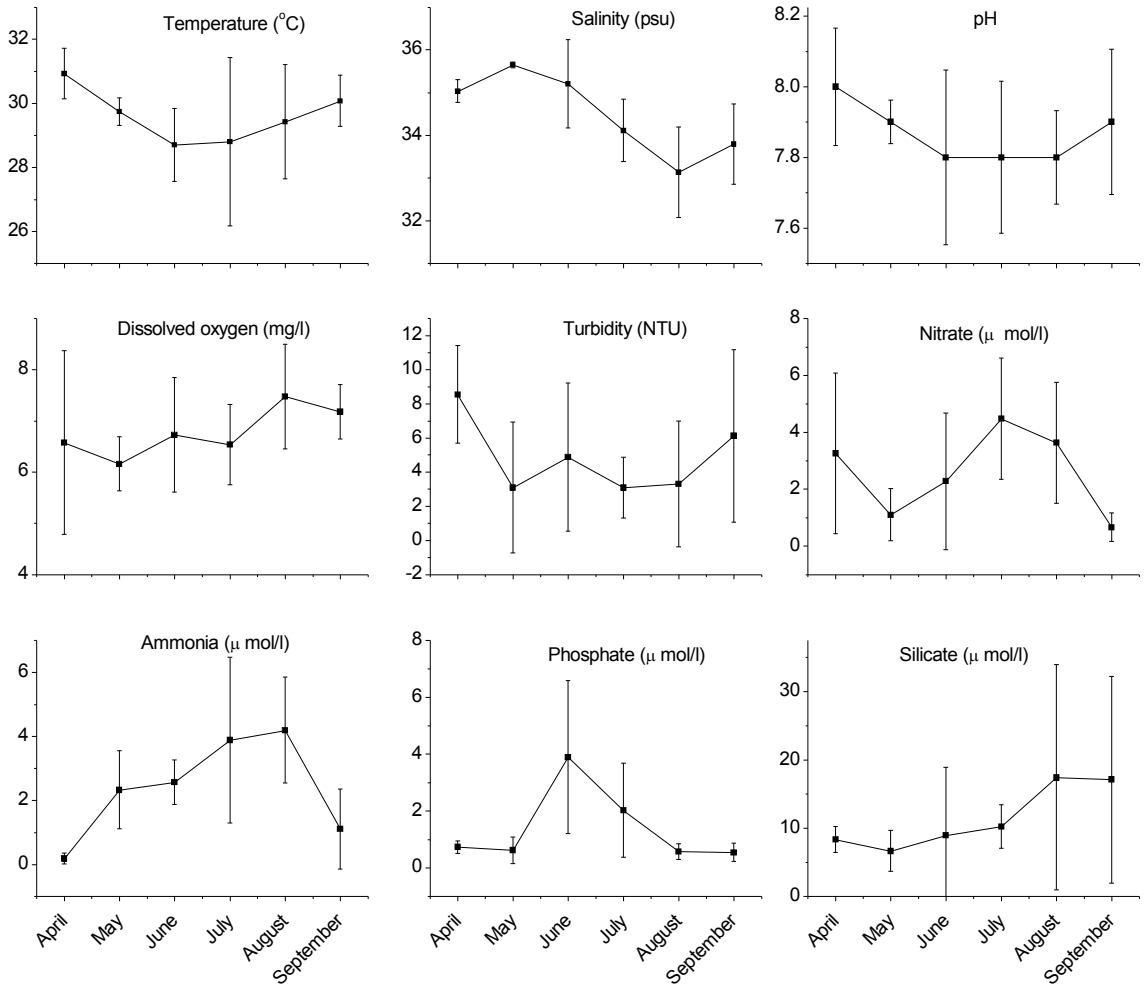

Figure-2: Variations in physic-chemical properties of coastal waters of Kalpakkam during April to September, 2008

Sorsogona tuberculata, *Pomadasys maculatum*, *Drepane punctata*, *Acentrogobius janthinopterus*, *Taenioides buchanani*, *Trypauchen vagina* and *Zebrias quagga* are amphidromous in nature while a few of them like *Cephalopholis formosa*, *Apogon multitaeniatus*, *Nemipterus peronii*, *Parascolopsis eriomma*, *Pterocaesio chrysozona*, *Chaetodon decussates*, *Apolemichthys xanthurus* and *Arothron hispidus* are of non-migratory nature.

Discussions

Fishes are fast swimmers and their passive movement along with water current is rarely reported unless otherwise during the migration between feeding and breeding grounds[18]. However, due to relatively high velocity of water inside the cooling system of power plants, they generally get impinged. Impingement of fishes in power plants is a common phenomenon; however, the present observation was an unusual one with the landing of large number of varieties of eels, box-fishes, porcupine fishes, puffer fishes, flat fishes and many others. The screens in the intake windows are taken out regularly for cleaning and maintenance purpose, which could be the plausible reason behind the observation of organisms bigger than screen mesh size. However, the present instance is important due to fact that such an event of fish impingement has not been reported so far in spite of the regular cleaning and maintenance of the intake screens. The number and composition of fish species observed within a short period of time generated interest to investigate the cause of this event. Processes which were thought to have influenced the fish impingement event are discussed briefly hereunder.

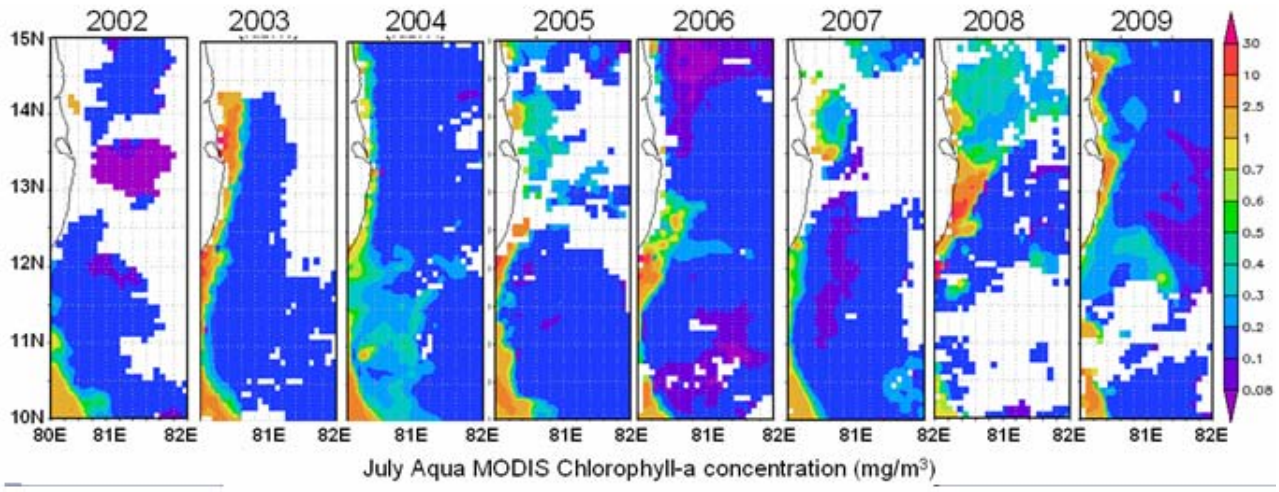

Figure-3: Variations in chlorophyll- a concentration in the southeast coast of India during July 2002-2009

Seasonal monsoon reversal of wind is a unique feature of Indian Ocean that results in consequent change in the circulation pattern[19-20]. Wind reversal occurs twice in a year between the southwest (SW) monsoon and northeast (NE) monsoon. In general, the SW to NE monsoon transition occurs during September/ October and the NE to SW transition occurs during February/ March. The pole-ward current during SW monsoon changes to equator-ward during the SW to NE monsoon transition, whereas, a reverse current pattern is observed during the transition period between NE to SW monsoon[21-23]. Subsequent to the change in the current pattern, alterations in coastal water quality and its biological properties have been reported[24-29]. The present event of impingement took place during SW monsoon during which the current direction was towards north. It has been reported that current velocity during SW monsoon is relatively high as compared to the southward current during NE monsoon[30]. Moreover, studies by others[31] have shown that during the SW monsoon wave heights reaches about 3 m due to the strong monsoon wind. The wind pattern at Kalpakkam during June-August is shown in the wind frequency distribution diagram (wind rose) which revealed relatively high wind flow from south, southeast and southwest (Figure-6). Apart from the above factors that might have influenced the fish impingement, the satellite data also showed an interesting feature as has been discussed in the result section. The fishes which were mostly reef-associated and demersal in nature might have drifted from the mid- and outer continental shelf regions into the coastal waters, along with the strong offshore current. The turbulent coastal waters could further have pushed the fishes towards shore leading to their entry into the cooling water system.

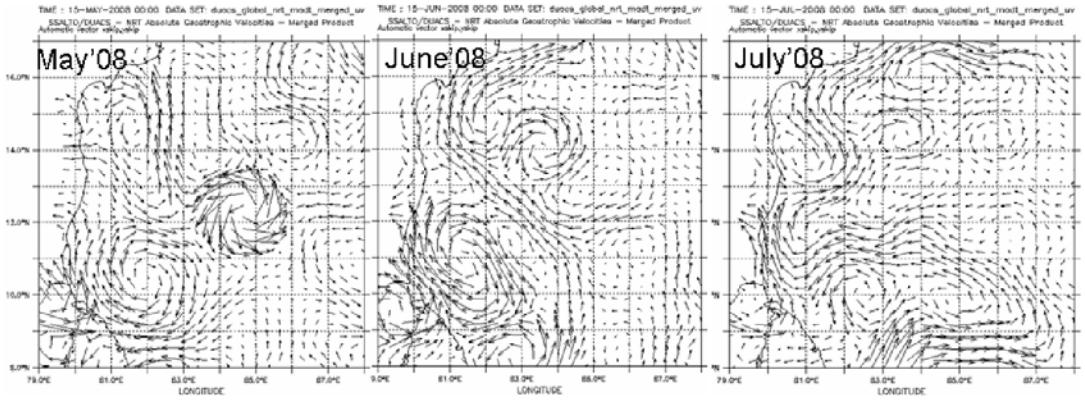

Figure-4: Circulation pattern in the coastal waters of southeast coast of India during May-July 2008

Upwelling is often considered as one of the important oceanographic phenomenon that can cause change in the hydrobiological characteristics of a region. Occurrence of localized upwelling in the coastal waters of Bay of Bengal during summer and southwest monsoon has been reported by many investigators[32-34]. Generally upwelling takes place in an approximately 40 km wide band (from land to seaward) throughout the east coast of India during this period, which gets relatively more intensified during SW monsoon[34]. A low temperature nutrient rich bottom water mass with or without biological components (plankton) replaces the surface water in the process of upwelling[33]. This often causes a high phytoplankton growth and some times it leads to bloom formation[35] due to conducive conditions like abundance of nutrients and a relatively low water temperature. These phytoplankton explosions attract the herbivores to which the carnivores follow. This process ultimately results in a temporary change in biodiversity of the area. In the present study, the coastal water was characterized by relatively low temperature and salinity typical of oceanic waters. Moreover, relatively high nitrate, ammonia and phosphate contents along with low plankton density in the coastal waters suggested the occurrence of upwelling. The phytoplankton and zooplankton density showed a peculiar trend. Though the zooplankton density was relatively high prior to the event, it followed the trend of phytoplankton density during the impingement. The above observation showed that the decrease in phytoplankton density was not due to grazing pressure but could be attributed to relatively low density of phytoplankton in the upwelling water. However, during the later stage of the study, a gradual increase in zooplankton density with increase in phytoplankton population was observed, which indicated that phytoplankton grew rapidly in presence of relatively high nutrient contents in the coastal waters. It is worthwhile to mention here that this part (Tamil Nadu) of the peninsular India receives bulk of its rainfall (~ 60%) from NE monsoon and the remaining from SW monsoon. The low rainfall during July 2008 (53 mm) and absence of any perennial river at this location supported the above observation of upwelling in the coastal waters of Kalpakkam, as freshwater runoff and precipitation could also have resulted in the above characteristics of the coastal waters. Though the role of upwelling in the fish impingement event could not be ruled out, a direct correlation between the two could not be established. It is important to mention here that a similar observation of enrichment of fishes along with other organisms in the catches of fishermen was reported from Kovalam coast of Tamil Nadu, about 40 km north of Kalpakkam, about two decades ago[36]. Interestingly, the authors[36] have attributed upwelling as the sole cause behind such an observation, which could also be true for the present one.

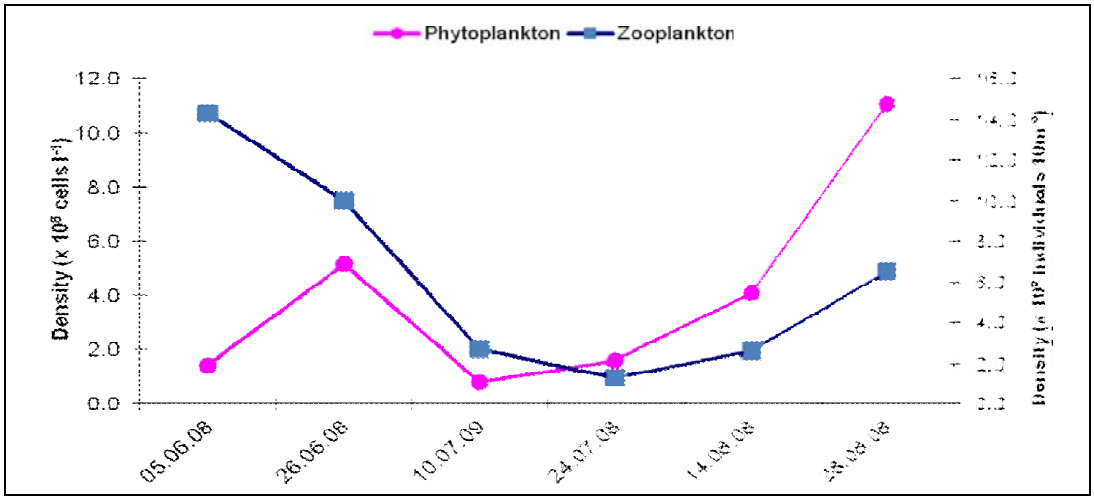

Figure-5: Variations in Phyto- and zooplankton density in the coastal waters of Kalpakkma during June-August 2008

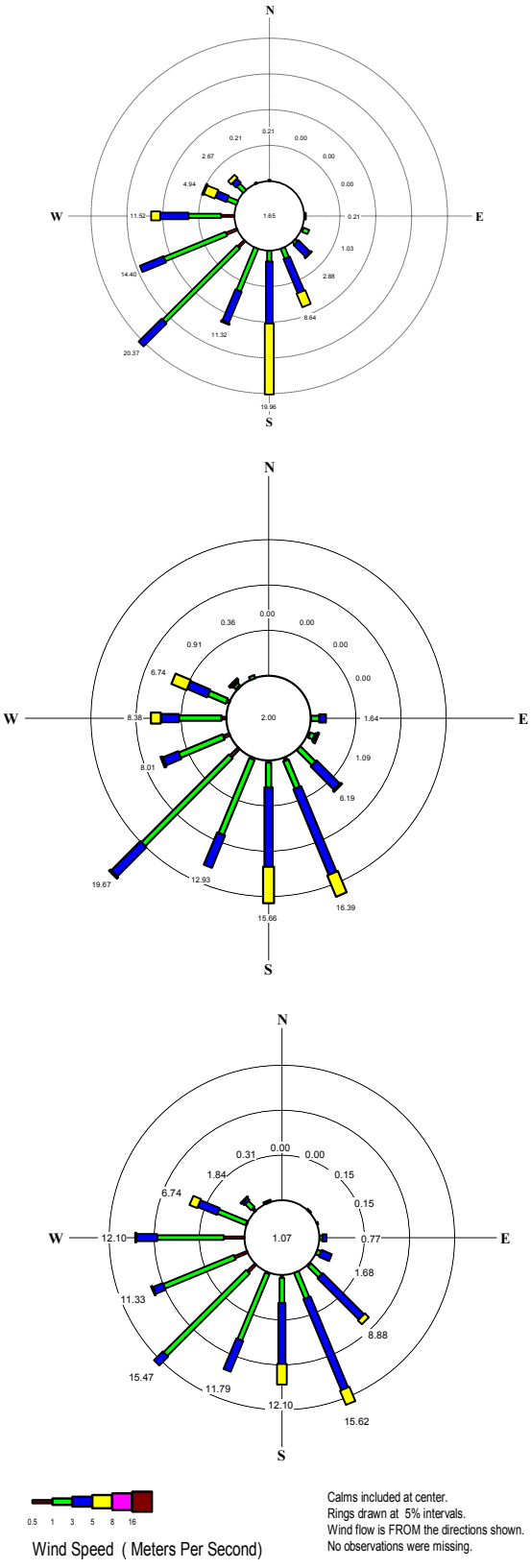

Figure-6: Wind frequency distribution at Kalpakkam during June-August 2008

AQUA MODIS data on chlorophyll-a showed that the coastal waters at this location was relatively more productive during the fish impingement period (July 2008) as compared to that of the years 2007 and 2009. The high phytoplankton density might have attracted the grazers and predators from the nearby areas. However, the plankton density enumerated from field sample collection during July was relatively low as compared to June and August. This showed that the impingement event could have taken place due to a synergistic effect of coastal circulation pattern, upwelling and coastal productivity rather than a single factor.

Conclusion

The present observation of unusual assemblage of reef-dwelling and demersal fishes very near to coast showed shoreward movement of deeper oceanic waters during the event of upwelling which intensifies at this location during the SW monsoon. Observation of relatively low temperature and high nutrient concentration particularly during the impingement period further supported the above theory of prevalence of upwelling in this region. Above study also depicted that this region, harbouring reefs and associated organisms highly sensitive to disturbances, is least impacted in terms anthropogenic activities.

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