Impact assessment of nuclear power plant discharge on zooplankton abundance and distribution in coastal waters of Kalpakkam, India

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Abstract

Background: Kalpakkam coastal area serves as fishing ground, influenced by anthropogenic effluents from its surrounding populations and backwaters.

Methods: The monthly abundance and distribution of zooplankton and some physico-chemical parameters were investigated in coastal waters near a nuclear power plant, Kalpakkam 2011. Zooplankton and surface water samples collected from three different locations (stations P1, P2 and P3) in the heated and non-heated parts of the coastal waters were analyzed using standard methods.

Results: Among all plankton genera in the cooling water, zooplankton was observed most sensitive group to entrainment-induced stress. Thirty genera were identified over the period of the investigation. Zooplankton population followed a trend as P1 > P3 > P2. A clear monthly variation and slight differences among stations were observed in terms of the zooplankton genera. The investigations revealed that changes in zooplankton genera across water bodies could be associated with differing temperature.

Conclusion: Our results clearly demonstrate that heated water discharge from the Madras Atomic Power Station has a negligible effect on zooplankton population at engineered canal near Plutonium Recycle Project (station P2). There is no impact on zooplankton population due to thermal effluent discharge into the coastal area (stations P1 and P3). Hence, further investigation is required to estimate the impact zone at either side during different seasons.

Keywords: Zooplankton, Physico-chemical parameters, Season, Kalpakkam, Nuclear power plant

Introduction

Water is a liquid compound and it covers 71% of the earth's surface in form of rivers, lake, and seas and is useful for survival of man, animals, and plants (CIA–The World Fact book: Central intelligence agency 2008-2009). Zooplanktonic organisms are one of the most important components of aquatic systems, which is used in the conversion of plant protein into animal protein (Terbiyik Kurt and Polat 2015). They are also used to construct the modern oceanic food webs and food source for larval fish and shrimp in natural water bodies (Damotharan et al. 2010). Coastal marine food web thus mainly activates in the presence of zooplankton. Zooplanktons are secondary producers that act as a central link with the primary producers, the phytoplankton and other organisms (Mitra et al. 2004). Compared to phytoplanktons, zooplanktons are larger and easier to identify and can act as valuable indicator of tropic status (Ward and Whipple 1966). In water pollution studies, few zooplankton species are used as "bioindicators" due to their occurrence, vitality, and responses. Prior to pollutants effect, bioindicators are useful in predicting the level and degree of the pollutants (Hao 1996; Ward and Whipple 1959).

In general, the ecological system and a measure of community pattern are described through plankton diversity. Noteworthy, seasonal changes control the

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diversity of plankton by the supply of plant nutrients (Magurran 1988; Barnese and Schelske 1994). Report from Baker and Hosny demonstrates the zooplankton diversity and abundance in coastal waters (Baker and Hosny 2005). Coastal zones located near to the nuclear and thermal power stations make use of large volumes of seawater for the cooling of generating units (Jahir Hussain et al. 2010). Consequently, marine life system gets affected by heated effluents from power plant which contains biofouling control agents. The thermal effluents thus significantly impact the food chain, which reflects directly or indirectly in the distribution and abundance of marine organisms. Also leads mechanical stress source to direct death of organisms and decrease in reproduction of zooplankton population (Kartasheva et al. 2008). Recently, numerous studies in anthropogenic impact, thermal discharges from power plant in to coastal waters, climate change, and modifications in biodiversity and biogeography are reported (Tseng et al. 2011).

Normally, the coastal environment is highly sensitive with great ecological and economic importance. It supports various communities and is directly or indirectly affected by anthropogenic activities (Cummins et al. 2004). It is known that the ocean and land margins are linked by coastal zones.

The human activities along estuarine and coastal waters enhance loading of huge volume of nutrient concentration that leads to environmental problems. The physico-chemical parameters monthly influence the variation in plankton distribution, abundance, and species diversity (Raymond 1983; Ezra and Nwankwo 2001). Generally, the physico-chemical variables were affected by seasonal variations and human activities along water body which could impacts the phytoplankton and zooplankton population. As explained by Gislason et al. 2014, the large-scale hydrographical conditions affect the variation in copepod species composition. It is well evident from various studies that the spatiotemporal distribution and abundance of planktonic organisms and fish larvae are influenced by seasonal variations of salinity, temperature, oxygen, turbidity, and food resources (Blaber et al. 1997; Harris et al. 1999; Barletta-Bergan et al. 2002a, b; Hoffmeyer et al. 2009; Ooi and Chong 2011; Williams et al. 2012). Also, a study showed that fishery activities are influenced by human activities in the bay (Terbiyik Kurt and Polat 2013).

It is worth investigating the wastes introduced into coastal zones by human activities along Kalpakkam coast, which could also affect the physico-chemical variables thus causing variation in abundance and distribution of
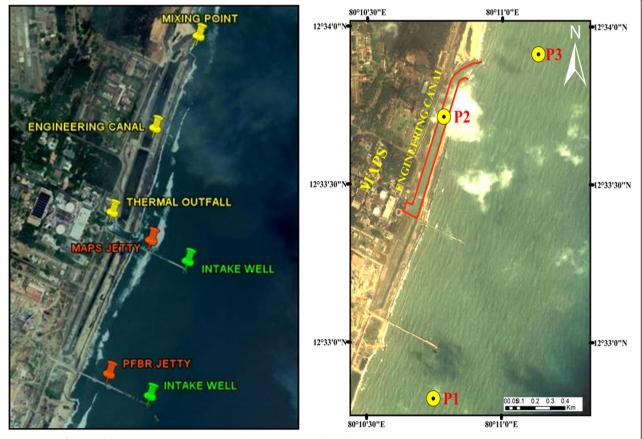

Fig. 1 Map of the sampling area. Dots represent sampling stations around Madras Atomic Power Station

plankton. However, there is limited information on the monthly abundance and distribution of zooplankton as well as the water quality around thermal discharge locations near nuclear power plant, Kalpakkam. The present study attempts to provide evidence about zooplankton with water quality for future references.

Materials and methods
Study area
Kalpakkam coast (12° 33 N and 80° 11 E) is situated about 80 km south of the mega city Chennai. A nuclear power plant (Madras Atomic Power Station, MAPS) and a desalination plant are located at southeast coast of India. MAPS consists of two units of pressurized heavy water reactor, each of 235 MW (e) capacities. Unit-1 reactor went operational on 23 July, 1983, whereas unit-2 reactor went operational on 18 September, 1985. The two reactors use seawater at the rate of 35 m³/s for the purpose of cooling the condenser. After extracting the heat, the heated effluent is released into the sea. The temperature gradient across the cooling water system from intake to outfall varies depending upon the level of power production and it is approximately 7 °C.
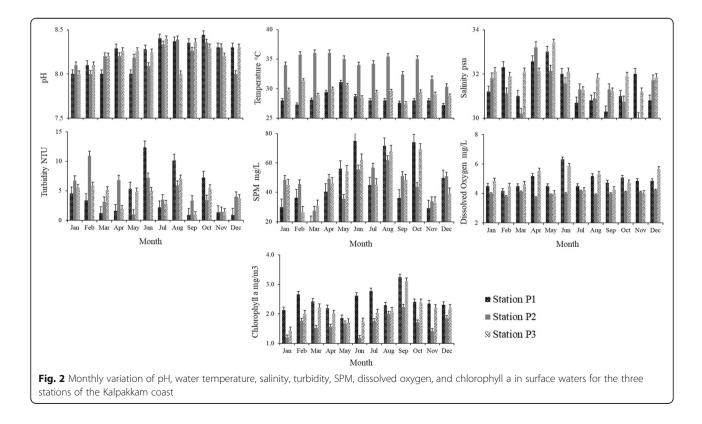
Sampling stations
Three sampling stations were chosen almost 2 km around the thermal power plant (Fig. 1). They were as follows:

Station 1: P1—200 m south of near Prototype Fast Breeder Reactor (PFBR)
Station 2: P2—Engineered Canal near Plutonium Recycle Project (PRP)
Station 3: P3—Near MAPS Mixing Point

Samples collection and analyses
Surface water and zooplankton samples were collected from the three stations around thermal power plant monthly between January 2011 and December 2011 (Fig. 1). Zooplankton samples were collected at monthly intervals through horizontal surface tows (nearly 5–10 m depth) using a typical zooplankton net with 0.35 m diameter and 158 μm mesh size and these samples were preserved in 5% buffered formalin solution used for qualitative analysis. A known quantity of water (50 L) was filtered through a bagnet of same mesh size and numerical analysis was carried out using Sedgewick-Rafter cell under the microscope for the quantitative analysis (ICMAM 1998). The zooplanktons were identified according to standard references from Newell and Newell (1977), Todd and Laverack (1991), Perumal et al. (1998), and Conway et al. 2003. Surface water samples were collected for physico-chemical analysis from all three stations. Environmental parameters such as pH, temperature, salinity, turbidity, suspended particulate matter (SPM), dissolved oxygen (DO), and chlorophyll-*a* (Chl-*a*) were analyzed according to standard

Fig. 2 Monthly variation of pH, water temperature, salinity, turbidity, SPM, dissolved oxygen, and chlorophyll a in surface waters for the three stations of the Kalpakkam coast

methods described by Strickland and Parsons (1972). A canonical correspondence analysis (CCA) (CANOCO for Windows 4.5) was performed to determine the statistical significance of the correlation between the environmental parameters and zooplankton (ter Braak and Smileuer 2002).

Results and discussion

Environmental variables

Hydrogen ion concentrations (pH) in surface waters remain alkaline throughout the study period at three stations with the maximum during the northeast monsoon and the minimum during pre- and post-monsoons. High pH was recorded in summer at station P3; it might be due to the influence of seawater penetration and high

biological activity (Govindasamy et al. 2000) and the occurrence of high photosynthetic activity (Saravanakumar et al. 2008). Surface water temperature was measured at station P1, P2, and P3; the values vary from 27.2 to 31.1 °C, 30.3 to 36 °C, and 27.5 to 31.4 °C, respectively (Fig. 2). The sudden drop at station P3 mainly occurs due to the result of turbulent mixing of the sea. Highest temperature (36 °C) is recorded in March and April and the lowest (27.2 °C) in December. The lowest temperature is due to strong land sea breeze and precipitation and the highest value could be attributed to high solar radiation (Das et al. 2002; Govindasamy et al. 2000; Santhanam and Perumal 2003). Temperature at outfall during this study period is about 8.4–9.6 °C greater than that at the intake, when the two units are operational. A

Table 1 Monthly distribution of dominant zooplanktonic genera at station P1

Genera	Genera No.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Acartia	G1	3.0	3.0	3.0	4.0	4.0	2.0	3.0	3.0	2.0	3.0	2.0	3.0
Acrocalanus	G2	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.0	2.0	2.0	3.0	2.0
Branchious	G3	3.0	3.0	3.0	3.0	3.0	2.0	3.0	2.0	3.0	2.0	2.0	2.0
Canthocalanus	G4	3.0	3.0	3.0	4.0	4.0	2.0	3.0	3.0	3.0	2.0	2.0	2.0
Centerophages	G5	3.0	3.0	3.0	2.0	3.0	3.0	2.0	2.0	2.0	3.0	2.0	2.0
Copilia	G6	3.0	3.0	3.0	2.0	2.0	3.0	2.0	2.0	2.0	2.0	2.0	2.0
Corycaeus	G7	3.0	3.0	3.0	2.0	3.0	2.0	3.0	3.0	3.0	2.0	2.0	2.0
Diphyes	G8	2.0	2.0	2.0	2.0	2.0	2.0	2.0	3.0	2.0	2.0	2.0	2.0
Eucalanus	G9	3.0	3.0	3.0	4.0	4.0	3.0	3.0	3.0	3.0	3.0	2.0	2.0
Euterpina	G10	3.0	3.0	3.0	3.0	3.0	2.0	3.0	3.0	3.0	2.0	2.0	2.0
Evadne	G11	3.0	3.0	3.0	4.0	4.0	3.0	3.0	3.0	2.0	2.0	2.0	2.0
Favella	G12	3.0	3.0	3.0	3.0	3.0	2.0	2.0	3.0	3.0	2.0	2.0	2.0
Globigerina	G13	2.0	3.0	3.0	2.0	3.0	2.0	3.0	2.0	2.0	2.0	2.0	2.0
Labidocera	G14	2.0	3.0	2.0	3.0	3.0	3.0	2.0	3.0	3.0	2.0	2.0	2.0
Lucifer	G15	3.0	3.0	3.0	3.0	3.0	3.0	2.0	3.0	3.0	2.0	2.0	2.0
Macrosetella	G16	2.0	3.0	3.0	2.0	2.0	2.0	3.0	2.0	2.0	2.0	2.0	3.0
Microsetella	G17	2.0	2.0	3.0	2.0	2.0	2.0	2.0	3.0	2.0	2.0	2.0	2.0
Monostyla	G18	3.0	2.0	2.0	2.0	3.0	3.0	3.0	2.0	2.0	2.0	2.0	2.0
Oithona	G19	3.0	3.0	3.0	3.0	3.0	2.0	3.0	3.0	2.0	2.0	2.0	2.0
Oncacea	G20	3.0	3.0	3.0	3.0	3.0	2.0	3.0	2.0	2.0	2.0	2.0	2.0
Paracalanus	G21	3.0	3.0	3.0	4.0	4.0	3.0	3.0	3.0	3.0	2.0	2.0	2.0
Sagitta	G22	3.0	3.0	3.0	3.0	4.0	3.0	3.0	3.0	3.0	2.0	2.0	2.0
Temora	G23	3.0	3.0	3.0	4.0	4.0	2.0	2.0	2.0	3.0	2.0	2.0	2.0
Tintinnopsis	G24	3.0	3.0	4.0	4.0	4.0	3.0	3.0	3.0	3.0	2.0	2.0	2.0
Bivalve veliger larva	G25	2.0	2.0	3.0	3.0	3.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Cirripede nauplii	G26	2.0	2.0	3.0	3.0	3.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Crustacean naupilus	G27	2.0	3.0	3.0	3.0	3.0	2.0	2.0	2.0	3.0	2.0	2.0	2.0
Copepod naupilus	G28	3.0	3.0	3.0	3.0	2.0	2.0	2.0	2.0	3.0	2.0	2.0	2.0
Gastropod veliger	G29	3.0	3.0	3.0	3.0	3.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Polycheate larve	G30	2.0	2.0	3.0	3.0	3.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0

(1.0 = rare; 2.0 = frequent; 3.0 = moderate; 4.0 = high)

smaller ΔT of 1.9–5.8 °C (with respect to the intake point temperature) is recorded at the mixing point.

Salinity ranges from 30.0 to 33.4 PSU and is high during post monsoon and low during the northeast monsoon at three stations. Higher values could be attributed to the low amount of rainfall, higher rate of evaporation, and neritic water dominance (Asha and Diwakar 2007). Turbidity and SPM vary from 0.90 to 18.10 NTU and 26.40 to 79.00 mg/L respectively. Station P2 records marginally higher turbidity compared to the others, which could be due to the occurrence of high turbulence owing to its closeness to MAPS outfall. Elevated dissolved oxygen levels are observed in June at station P1 and P3. Chl-*a* concentration at station P1 and P3 is comparable (Fig. 2). The low Chl-*a* at station P2

than P1 may be attributable to grazing taking place inside the intake tunnel which is recovered at the mixing point.

Zooplankton abundance and distribution

The members of zooplankton recorded during the study are as follows: Ciliata, Foraminifera, Siphonophora, Cladocera, Rotifera, Copepoda, Harpacticoida, Cyclopoida, Poecilostomatoida, Decapoda, Chaetognatha, and larval plankton. Tables 1, 2, and 3 presented the genera compositions of zooplankton from all the three stations. A total of 24 genera (G) of zooplankton are identified along with six larval plankton which include two that belonged to Ciliata, one to foraminifera, one to Siphonophora, one to Cladocera, two to Rotifera, eight to

Table 2 Monthly distribution of dominant zooplanktonic genera at station P2

Genera	Genera No.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Acartia	G1	2.0	3.0	3.0	4.0	3.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Acrocalanus	G2	2.0	2.0	3.0	3.0	3.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Branchious	G3	2.0	2.0	3.0	2.0	3.0	1.0	1.0	1.0	2.0	1.0	2.0	2.0
Canthocalanus	G4	3.0	3.0	3.0	3.0	3.0	2.0	2.0	2.0	1.0	2.0	2.0	2.0
Centerophages	G5	2.0	2.0	3.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Copilia	G6	2.0	2.0	2.0	2.0	2.0	2.0	1.0	2.0	1.0	2.0	2.0	2.0
Corycaeus	G7	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.0	2.0	2.0	2.0
Diphyes	G8	2.0	2.0	2.0	2.0	2.0	1.0	2.0	2.0	1.0	2.0	2.0	1.0
Eucalanus	G9	2.0	2.0	2.0	3.0	2.0	2.0	2.0	2.0	1.0	2.0	1.0	2.0
Euterpina	G10	2.0	2.0	2.0	3.0	2.0	2.0	2.0	2.0	1.0	2.0	2.0	2.0
Evadne	G11	3.0	3.0	2.0	4.0	4.0	2.0	2.0	2.0	2.0	2.0	1.0	2.0
Favella	G12	2.0	2.0	2.0	2.0	3.0	1.0	1.0	2.0	2.0	2.0	2.0	2.0
Globigerina	G13	2.0	2.0	2.0	2.0	2.0	1.0	2.0	1.0	1.0	1.0	1.0	2.0
Labidocera	G14	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Lucifer	G15	2.0	2.0	2.0	2.0	2.0	2.0	1.0	2.0	1.0	2.0	2.0	2.0
Macrosetella	G16	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.0	1.0	2.0	2.0
Microsetella	G17	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.0	1.0	1.0	2.0	2.0
Monostyla	G18	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.0	1.0	1.0	2.0	2.0
Oithona	G19	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.0	1.0	1.0	2.0
Oncacea	G20	2.0	2.0	2.0	2.0	3.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Paracalanus	G21	2.0	3.0	2.0	2.0	3.0	2.0	2.0	2.0	2.0	1.0	2.0	1.0
Sagitta	G22	2.0	2.0	2.0	3.0	2.0	2.0	2.0	2.0	2.0	1.0	1.0	2.0
Temora	G23	2.0	2.0	2.0	3.0	3.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0
Tintinnopsis	G24	2.0	2.0	2.0	4.0	4.0	1.0	2.0	2.0	2.0	1.0	1.0	2.0
Bivalve veliger larva	G25	2.0	2.0	3.0	3.0	3.0	2.0	1.0	2.0	2.0	2.0	2.0	2.0
Cirripede nauplii	G26	2.0	2.0	2.0	3.0	2.0	2.0	2.0	2.0	2.0	2.0	3.0	2.0
Crustacean naupilus	G27	2.0	2.0	2.0	3.0	2.0	2.0	2.0	2.0	2.0	2.0	3.0	2.0
Copepod naupilus	G28	2.0	2.0	2.0	2.0	3.0	2.0	2.0	2.0	2.0	3.0	2.0	2.0
Gastropod veliger	G29	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Polycheate larve	G30	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0

(1.0 = rare; 2.0 = frequent; 3.0 = moderate; 4.0 = high)

Table 3 Monthly distribution of dominant zooplanktonic genera at station P3

Genera	Genera No.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Acartia	G1	3.0	3.0	3.0	3.0	3.0	2.0	3.0	2.0	2.0	3.0	2.0	2.0
Acrocalanus	G2	3.0	2.0	3.0	3.0	3.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Branchious	G3	2.0	3.0	3.0	2.0	2.0	2.0	3.0	2.0	3.0	2.0	2.0	2.0
Canthocalanus	G4	3.0	3.0	3.0	3.0	3.0	2.0	3.0	3.0	3.0	2.0	2.0	2.0
Centerophages	G5	3.0	2.0	3.0	2.0	2.0	3.0	2.0	2.0	2.0	3.0	2.0	2.0
Copilia	G6	2.0	2.0	3.0	2.0	2.0	3.0	2.0	2.0	2.0	2.0	2.0	2.0
Corycaeus	G7	2.0	3.0	3.0	2.0	2.0	2.0	3.0	3.0	3.0	2.0	2.0	2.0
Diphyes	G8	2.0	2.0	2.0	3.0	2.0	2.0	2.0	3.0	2.0	2.0	2.0	2.0
Eucalanus	G9	3.0	3.0	3.0	3.0	4.0	3.0	2.0	3.0	2.0	3.0	2.0	2.0
Euterpina	G10	2.0	3.0	3.0	3.0	2.0	2.0	3.0	3.0	3.0	2.0	2.0	2.0
Evadne	G11	3.0	3.0	3.0	3.0	4.0	3.0	2.0	3.0	2.0	2.0	2.0	2.0
Favella	G12	2.0	2.0	3.0	3.0	3.0	2.0	2.0	3.0	3.0	2.0	2.0	2.0
Globigerina	G13	2.0	2.0	3.0	2.0	2.0	2.0	3.0	2.0	2.0	2.0	2.0	2.0
Labidocera	G14	2.0	3.0	2.0	3.0	3.0	3.0	2.0	3.0	2.0	2.0	2.0	2.0
Lucifer	G15	3.0	2.0	3.0	3.0	3.0	3.0	2.0	3.0	3.0	2.0	2.0	2.0
Macrosetella	G16	2.0	3.0	3.0	2.0	2.0	2.0	3.0	2.0	2.0	2.0	2.0	2.0
Microsetella	G17	2.0	2.0	2.0	2.0	2.0	2.0	2.0	3.0	2.0	2.0	2.0	2.0
Monostyla	G18	2.0	2.0	2.0	2.0	2.0	3.0	2.0	2.0	2.0	2.0	2.0	2.0
Oithona	G19	3.0	2.0	2.0	2.0	3.0	2.0	3.0	3.0	2.0	2.0	2.0	2.0
Oncacea	G20	3.0	3.0	2.0	3.0	3.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Paracalanus	G21	3.0	3.0	3.0	3.0	3.0	3.0	2.0	3.0	3.0	2.0	2.0	2.0
Sagitta	G22	3.0	3.0	2.0	3.0	3.0	2.0	3.0	3.0	3.0	2.0	2.0	2.0
Temora	G23	2.0	2.0	3.0	3.0	4.0	2.0	2.0	2.0	3.0	2.0	2.0	2.0
Tintinnopsis	G24	2.0	3.0	3.0	3.0	4.0	3.0	3.0	3.0	3.0	2.0	2.0	2.0
Bivalve veliger larva	G25	2.0	2.0	3.0	3.0	3.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Cirripede nauplii	G26	2.0	2.0	3.0	3.0	3.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
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Copepod naupilus	G28	2.0	2.0	3.0	3.0	2.0	2.0	2.0	1.0	2.0	2.0	2.0	2.0
Gastropod veliger	G29	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Polycheate larve	G30	2.0	2.0	3.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0

(1.0 = rare; 2.0 = frequent; 3.0 = moderate; 4.0 = high)

Copepoda, three to Harpacticoida, one to Cyclopoida, three to Poecilostomatoida, one to Decapoda, one to Chaetognatha, and also six larvae (Tables 1, 2, and 3).
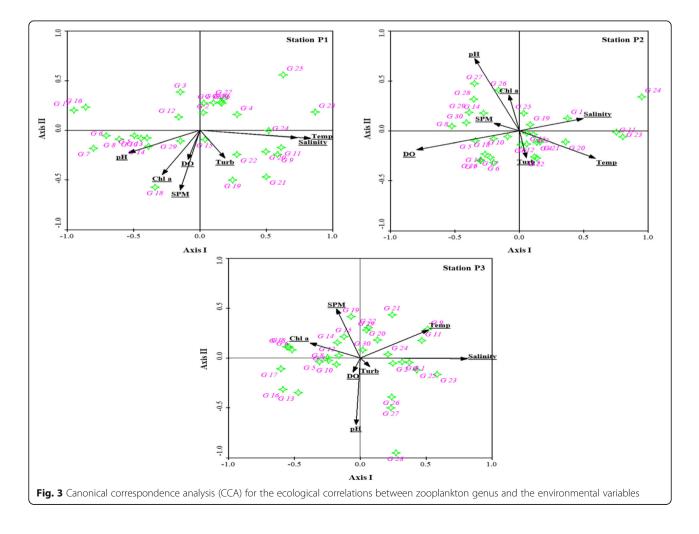
Numerically, zooplankton genera count at three locations vary as 423–771 cells/ml (P1), 354–632 cells/ml (P2), and 414–754 cells/ml (P3). On the whole, copepods contribute the dominant population and the order of various groups are copepoda > larvae plankton > Harpacticoida and Poicilostomatoida > Rotifera and Ciliata > Foraminifera, Siphonophora, Cladocera, Cyclopoida, Decapoda, and Chaetognatha. The warm water discharged by the power plant increases the temperature of the surrounding sea water causing physiological stress; on the other hand, it also acts as physical forcing by modulating the direction of the water current. So, the discharge from MAPS not only exerts temperature stress on copepods but also influences the distribution pattern by changing the direction of the water currents.

Calanoid copepods absolutely dominate the copepod abundance throughout a year. Although the small-body-sized genus, *Paracalanus*, are dominant in all stations, the composition of calanoid communities is different between the sites and is almost three times higher at station P1 (Table 1). Copepod genus throughout the study period is similar in station P1 and station P3 with the dominance of *Paracalanus*, *Temora*, and *Acartia*. Large calanoid copepods including *Canthocalanus* and *Eucalanus* are often abundant at station P1, but they are rarely found at station P2. In station P3, both *Paracalanus*

and *Temora* dominate, whereas copepod community is present throughout the study period. Similar observation on copepods abundance was recorded by Santhanam and Perumal 2003 and Damotharan et al. 2010. Abundance of zooplankton fluctuates in accordance with salinity regime in the Kalpakkam coastal area. However, in all stations, rotifers are rarely found, although their occurrence is seasonal. The fish larvae were commonly found in all stations. This presence shows that the environment is suitable for a breeding and acts as nursery for a variety of fishes in coastal ecosystem (Damotharan et al. 2010). According to Townsend et al. (2000) and Miller (2005), plankton communities assist as a base for the food web chain that supports the commercial fisheries. The stable environmental condition and presence of neritic element that prevails higher zooplankton density during summer (Padmavati and Goswami 1996). Low population density is observed in northeast monsoon due to the hydrographically washable condition.

Presence of *Tintinnopsis* proves a salinity tolerance and the recorded higher density in summer might be due to the influence of neritic waters. *Acrocalanus* and *Paracalanus* are common forms found in all stations which might be due to their ability to adapt to the prevailing environmental conditions. *Evadne* is abundant at station P2, perhaps due to its thermal tolerance. Crustacean larvae occur very sparsely at all the stations. The absence of crustacean larvae indicates that the area is not a rich habitat for shrimps in the coastal area. In terms of population, station P1 (PFBR) is the richest zone followed by station P3 (Near MAPS mixing point) and station P2 (PRP outfall). Abundance of zooplankton in the Kalpakkam coast is the highest during summer and the lowest during the northeast monsoon.

Influence of the environmental variables on zooplankton

CCA performed on the basis of their Dominant Index (Y) reveals the influence of genus-environmental variables and genus-month wise in all three stations. In this procedure, the environmental variables appear from the origin of the ordination as vectors. The importance of relationship between the environmental variable with

Fig. 3 Canonical correspondence analysis (CCA) for the ecological correlations between zooplankton genus and the environmental variables
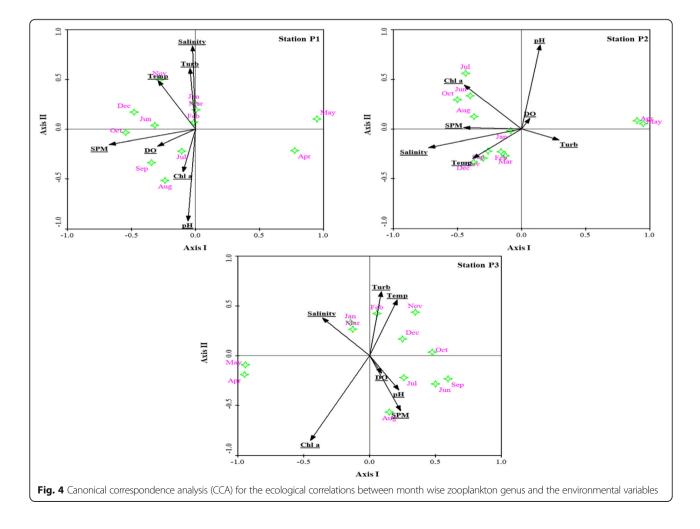
zooplankton genus and month was based on length of the vector represents.

In station P1, the second axis exposes that *Lucifer* is affected by turbidity. Temperature and salinity act as controlling factor for zooplankton; *Evadns*, *Eucalanus*, and *Oncacea* prefer high temperature and salinity. The plankton abundance and distribution are affected by seasonal variations of some physico-chemical parameters (Ezra and Nwankwo 2001). *Labidocera* and *Gastropod veliger* relies on pH (Fig. 3). Station P2 CCA plot (Fig. 3), *Acartia* and *Oithona* is influenced by salinity. *Acrocaranus*, *Canthocalanus*, *Lucifer*, *Oncacea*, and *Paracalanus* are affected by the temperature, while *Eucalanus* and *Favella* are sensitive to turbidity. *Centerophages*, *Euterpina*, and *Monostyla* exist in high DO concentration. *Cirripede nauplii* and *Crustacean naupilus* are mostly associated with high pH. *Eucalanus*, *Evadns*, and *Tintinnopsis* are affected by temperature, while salinity presents as orthogonal in axis. *Favella* and *Lucifer* are affected by Chl-*a* and SPM in station P3. The present observations prove that changes in zooplankton community in all stations might be associated with salinity.

The southwest monsoon influences the environmental variables such as pH, SPM, Chl-*a*, and DO in station P1. The fourth axis separates temperature, turbidity, and salinity, and most of the collections were in post monsoon and northeast monsoon (Fig. 4). According to the fourth axis in station P2, the only environmental factor is Chl-*a* which is mostly influenced by southwest monsoon, whereas SPM falls orthogonal. In station 3, first axis divides temperature with turbidity and most of these groups fall into the northeast monsoon. The second axis separates with pH, SPM, and DO were influenced by southwest monsoon. Salinity forms the third axis, its impact in late post monsoon and loosely related with January and March. Accord to ecological systems, the above comparisons highlight that the seasonal fluctuation of environmental variables may affect the zooplankton species (Drake and Arias 1991; Strydom 2003; Potter et al. 2015).

Conclusion

Based on the present observation, the study has proved that Kalpakkam coastal waters are relatively unpolluted

Fig. 4 Canonical correspondence analysis (CCA) for the ecological correlations between month wise zooplankton genus and the environmental variables

with rich zooplankton diversity and enough physico-chemical status to support plankton population. The abundance of zooplankton in the coastal waters of Kalpakkam is influenced by three factors: water movements, fish predation, and heating by the power station. Our data showed a clear pattern of zooplankton distribution with an increase in temperature and distance from the outfall to mixing zone. Over the study period, G1 to G30 zooplankton genera were recorded at all stations and also found that fluctuation from station to station. Distribution of genera is intermittently presented in the station P2 due to thermal effluent discharged through engineered canal. Data from field studies suggest that distribution of zooplankton population is dependent on thermal stress around the cooling water discharge, whereas station P1 was unaffected zone. The environmental factors can influence the distribution of zooplankton. The relationship between zooplankton genera and environmental parameters varied according to the genera and seasonal cycle. Temperature and salinity are the key factors influencing the distribution and abundance of zooplankton. Present knowledge on impact of MAPS effluents on marine life is sketchy; hence, further in-depth investigation is required to estimate the impact zone at either side during different seasons. This observation is used as basic information of the zooplankton distribution and abundance for further ecological assessment and monitoring of these coastal ecosystems.

Abbreviations

CCA: Canonical correspondence analysis; Chl-*a*: Chlorophyll-*a*; DO: Dissolved oxygen; G: Genera; ICMAM: Integrated coastal and marine area management; MAPS: Madras Atomic Power Station; MW (e): Megawatt electrical; P1, P2 and P3: Station name; PFBR: Prototype Fast Breeder Reactor; pH: Hydrogen ion concentrations; PRP: Plutonium Recycle Project; SPM: Suspended particulate matter; *Y*: Dominant index

Availability of data and materials

Please contact the corresponding author for data requests.

Authors' contributions

Anna University and IGCAR designed and conducted the field research, analyzed the data, and interpreted the results and helped in writing the manuscript. All authors read and approved the final manuscript.

Ethics approval and consent to participate

Not applicable in this section.

Consent for publication

Not applicable in this section.

Competing interests

The authors declare that they have no competing interests.

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