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Study on distribution pattern of Zooplankton community structure in Thane Creek, Maharashtra, India.

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ABSTRACT

Estuaries and creeks are important ecological systems because the combination of freshwater and saltwater provides distinct habitats that sustain a variety of marine life. This study, conducted between January and April 2023, assessed spatiotemporal variation of microzooplankton and mesozooplankton diversity and distribution along Thane Creek, west coast of India. The tidal action influences the ecosystem known for its importance as a breeding ground for commercially valuable fish and crustaceans. According to the findings, there may be indications of eutrophication in the area, as zooplankton population is inversely related to nutrient and chlorophyll-a concentrations. Microzooplankton and Mesozooplankton abundance increased from the higher creek (Sampling Station S1) to the lower creek (Sampling Station S8), demonstrating the relevance of these habitats for zooplankton communities. While diversity varied across both extremes, mesozooplankton and microzooplankton abundance increased from high chlorophyll-a stations to high salinity gradient sites. Copepod groups predominated throughout the research, with Oithona sp. present at all sampling points. The majority of the biomass is composed of copepods, chaetognaths, polychaetes, hydrozoans, decapods, and *Acetes sp*. These findings give information on the geographical dynamics of Thane Creek's zooplankton groups and their response towards environmental changes, particularly eutrophication. Understanding these trends is critical for effective management and conservation efforts aimed at protecting the biodiversity and ecological health of this significant estuarine ecosystem.

Keywords: Microzooplankton, Mesozooplankton, Diversity, Abundance, Copepods, *Acetes indicus.*

INTRODUCTION

Plankton are a diverse group of organisms that are characterized by their small size and limited swimming ability, and are found throughout the world's oceans, lakes, and rivers. (Carstensen et al., 2015). Plankton play an important role in marine ecosystems, serving as the base of the food chain and providing food for larger organisms. Zooplankton, as lower trophic level animals, assist us in understanding the ecological destiny of a water body by analysing its composition, distribution, and community structure. Changes in water quality characteristics such as temperature, salinity, nutrients, and contaminants can affect various zooplankton species, as noted by Mishra and Panigrahy (1999). According to Nair et.al. (1999), the zooplankton community is composed of herbivores, omnivores, and carnivores, with herbivores generally being the most prevalent. Zooplankton, as primary consumers, play a significant role in the food chain and are a major food source for crustaceans, molluscs, and fishes. Thus, the abundance of zooplankton practically acts as an index to assess the fertility of water mass. The accurate understanding of fishery resources requires a thorough investigation into the distribution, intensity, and abundance of zooplankton in relation to environmental factors (Sarkar et.al; 1985). Some fishes rely solely on zooplankton as their food source, so their presence is directly connected to the abundance of zooplankton, as stated by Nasser et al. (1998). Understanding the taxonomy and systematics of species is crucial for assessing their ecological significance, distribution, diversity, and their ability to adapt to environmental changes. Given these perspectives, extensive research has been conducted on zooplankton. Biologists such as Nair et.al (1991), Desai et.al. (1983), Madhupratap (1987), Srinivasa, and others have mainly reported on zooplankton studies in Indian waters. The zooplankton data on the Thane creek, have been reported by Desai et.al. (1977), Gajbhiye (1979 & 1982), Lodh (1990), Gokhale & Athalye (1995), and Goldin (2001). Lodh (1990) studied both phytoplankton and zooplankton distribution from nearshore waters of Mumbai including a part of Ulhas River estuary. They also contribute to the biogeochemical cycling of elements, such as carbon and nitrogen, and play a critical role in regulating Earth's climate by sequestering carbon dioxide from the atmosphere (Behrenfeld et al., 2005; Falkowski et al., 2000).

Analysis of sewage pollution at the outfalls are carried out enhancing the satellite data of Thane Creek at Mulund, Bhandrup, Vasi and Ghatkopar, Vasi, Chembur, Sewari and off the Mumbai Port area. The spread areas of sewage pollution estimated on 21 February 2002 indicated larger areas of coverage in the upper creek than those observed in the lower creek.

Table 1.1: Classification of plankton based on size (Schutt et al., 1892; Gajbhiye et al., 2002)

Plankton	Size range and examples
Ultraplankton	0.2-2μm (Marine viruses, small eukaryotic bacteria, protozoans)
Nanoplankton	2-20μm (Heterotrophic nanoflagellates feeding on bacteria)
Microplankton	20-200μm (Ciliates)
Mesoplankton	200-2000μm (Copepods, Decapod larvae, Polychaete larvae, Ostracods)
Megaplankton	>2000 μm (Jellyfish)

Significance of Mesozooplankton:

Mesozooplankton are an important component of the pelagic food web, as they transfer energy from the lower to higher trophic levels (Calbet, 2001). The mesozooplankton community is sensitive to varying oceanographic conditions (Keister et al., 2012) and their short life cycle and quick community-level response to environmental changes are measurable variables (Siokou-Frangou, 1996). Hence, knowledge on species composition, abundance, distribution and diversity of mesozooplankton is of great significance in biological oceanography (Kuipers et al., 1993; Dvoretsky et al., 2015). In recent decades, eutrophication due to anthropogenic activities has altered coastal and marine systems and associated biota (Smith et al., 1999; Häder et al., 2020). Further, seasonal changes of environmental variables are major drivers in the fluctuation of primary and secondary production (Barber et al., 2001).

Significance of Microzooplankton:

Microzooplankton (MZP) are a group of heterotrophic microplankton in the size range of 20-200 μm (Porter et al. 1985). With the exception of sarcodines and crustacean larval stages, heterotrophic ciliates and dinoflagellates make up the majority of the 20–200 m-sized microzooplankton species. By consuming 20–100% of the primary output, they contribute significantly to the flow of carbon in marine ecosystems (Gast, 1985; Pierce and Turner, 1992; Riley, 1965; Beers and Stewart, 1970; Heinbokel and Beers, 1979; Capriulo and Carpenter, 1983; Frost, 1991; Landry, et al., 1998). In addition to directly ingesting bacteria, micro zooplankton also play trophic intermediary roles between smaller mesozooplankton grazers and bacterioplankton (Gast, 1985; Sherr and Sherr, 1987; Reid and Karl, 1990), as well as in the regeneration of nutrient-rich waters (Goldman et al., 1987; Probyn, 1987). In particular, where microzooplankton serve as the mediator route for the uptake of organic carbon and thus influence biogeochemical cycles, it is thought that less organic carbon leaves the euphotic zone as a result of the close coupling between microbial and microzooplankton components of the aquatic food webs. Studies from India's west coast (Madhupratap et al., 1992, 1996; Gauns et al., 1996; Gauns et al., 2005; Jyothibabu et al., 2008; AshaDevi et al., 2010) show that the microzooplankton population is an important part of the area's food web. Except for Cochin backwaters (Jyothibabu et al., 2006), there hasn't been any research on microzooplankton in any of the estuaries along India's west coast. Such investigations are necessary for a thorough understanding of their function in tropical estuary systems.

MATERIALS & METHODS

Study area:
The study area of Thane Creek is systematically divided into upper and lower sections to facilitate a comprehensive analysis of the zooplankton community across varying environmental conditions. The upper creek stations, located in the northern region, include Kopri (S1), Airoli (S2), Ghansoli (S3), and Koparkhairane (S4). These stations are characterized by their proximity and possibility to freshwater inflows and urban influences, which may impact the physicochemical parameters of the water column. In contrast, the lower creek stations are situated in the southern region and comprise Upper Vashi (S5), Lower Vashi (S6), Trombay (S7), and Seawoods (S8). This segment of the creek is influenced by tidal dynamics and saline conditions.

Thane Creek's hydrodynamic nature is influenced by its position (72°55 to 73°00 E and 19°00 to 19°15 N) and the ecosystem around it. It has mangrove mudflats on both banks. The creek is tidal, which means it is influenced by the flow of tides. The state of Maharashtra is located on India's northern west coast (Fig no. 1). The Thane estuary has a depth of 12 m at the inlet and gradually decreases in depth as one moves upstream (Thomas et al. 2019). The stream is also utilized to dump solid garbage in order to restore mangrove swamps for residential development and roads are constructed (Quadros et al., 2009).

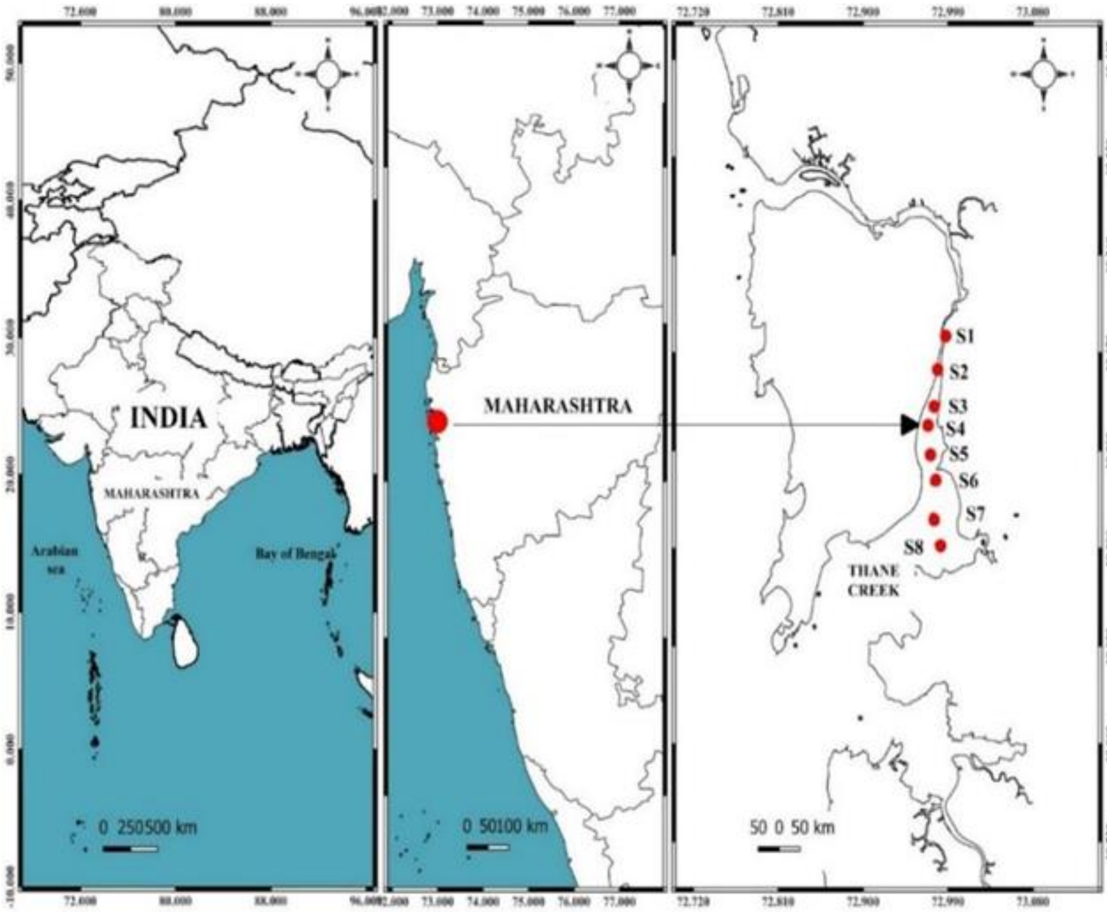


Figure 1 : Study area and Sampling Site

Table 2: Sampling Station

Location	Station code	Co-ordinates
Kopri	S1	19°11'9.59"N 72°59'9.44"E
Airoli	S2	19° 9'16.99"N 72°58'50.58"E
Ghansoli	S3	19° 7'16.26"N 72°58'23.35"E
Kopar Khairane	S4	19° 6'8.26"N 72°58'14.17"E
Upper Vashi	S5	19° 4'36.79"N 72°58'14.28"E
Lower Vashi	S6	19° 3'2.88"N 72°58'28.02"E
Trombay	S7	19° 1'8.87"N 72°58'26.84"E
Seawoods	S8	18°59'35.01"N 72°58'46.88"E

Thane Creek receives approximately litres of domestic sewage and industrial wastewater. The turbulence and advection caused by the tides would significantly dilute the concentrations of these toxins. According to Gupta (2003) & Sasamal et al. (2007), the upper creek is the most polluted. Pollutants entering the creek upstream of the Vashi bridge are expected to fluctuate throughout the creek system, and discharge into the Arabian Sea will be a drawn-out process due to the creek's reliance on tides and currents for waste absorption. (Refer, Fig. no. 1 and Table no. 2).

Method of water sample collection:
The Surface creek water samples were collected from different sampling locations. The sampling bottles were pre washed with low grade alcohol.

Methodology for physicochemical parameters of water

1. Environmental Parameters:
Temperature and pH Measurement:
Atmospheric and water temperatures were measured using a handheld mercuric thermometer. The pH of water samples was assessed with a pH meter (Model: EUTECH-pH 700), calibrated with standard buffers prior to use. **Salinity Determination:** Salinity was calculated using the Argentometric method. A known volume of water was titrated with silver nitrate in the presence of potassium chromate, with the formula applied: Salinity = 0.03 + (1.805 × Chlorinity).

2. Chemical Analysis
Dissolved Oxygen (DO) and Biological Oxygen Demand (BOD):
DO and BOD were measured using Winkler's method. Bottles were filled to overflow to eliminate air bubbles, and 1 mL of Winkler's A and B reagents were added. After mixing, the precipitate was allowed to settle for 15 minutes, then titrated with sodium thiosulfate until a blue endpoint was reached. The calculations followed:

$$\text{DO OR BOD} = \frac{B.R.\ x\ normality\ of\ Na_2S_2O_3\ x\ 8\ x\ 1000}{Volume\ of\ Sample}$$

Total Suspended Solids (TSS):
TSS was determined by filtering a water sample through a pre-weighed filter. The filter was dried at 103–105°C until weight stabilization, and the increase represented TSS.

3. Nutrient Analysis: Nitrite-Nitrogen (NO2-N): Measured by the method of Bendschneider and Robinson (1952), which involves the formation of a diazo compound that reacts with N L-naphthyl ethylenediamine dihydrochloride, yielding an azo dye measured at 543 nm. **Nitrate-Nitrogen (NO3-N):** NO3-N was quantitatively reduced to nitrite using amalgamated cadmium granules, maintaining stable pH with ammonium chloride buffer (Grasshoff, 1983). **Ammonia-Nitrogen (NH4-N):** Determined via the indophenol blue method (Koroleff, 1983), where ammonia forms indophenol blue in a moderately alkaline medium, with absorbance measured at 630 nm. **Phosphate-Phosphorus (PO4-P):** Inorganic phosphate was determined by forming a reduced phospho-molybdenum blue complex (Grasshoff, 1983), with absorbance measured at 882 nm. **Silicate-Silica (SiO4-Si):** Dissolved silicate was analyzed based on the formation of yellow silico-molybdic acid, reduced to a blue complex and measured at 810 nm (Grasshoff, 1983).

4. Biological Parameters: Chlorophyll-*a* (Chl *a*): Phytoplankton biomass was estimated by filtering 500 mL of water, extracting pigments in 90% acetone, and determining concentration spectrophotometrically according to Lorenzen's equation (1967).

Mesozooplankton Collection:
Mesozooplankton were collected using a Heron Tranter (HT) net (mesh size 0.2 mm) through oblique hauls. A calibrated flow meter (General Oceanics, USA) recorded water flow (Goswami et al., 2005). (Refer, Fig. no. 2).

Figure no. 2. Heron Tranter net hauling with a flow meter

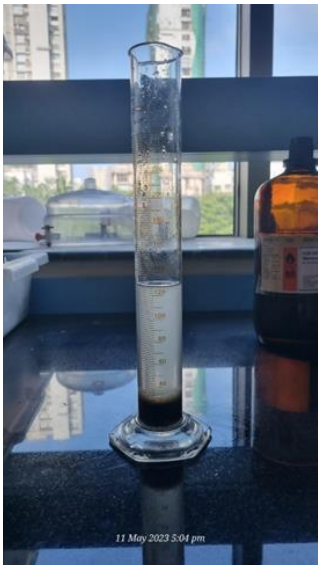


Figure 3: Estimation of biomass using volumetric method

Sample Preservation:
Collected samples were preserved in airtight containers with 10% formaldehyde, stored below 25°C and away from direct sunlight.

5. Sample Analysis: Biomass Estimation: Biomass and taxa enumeration were performed. Biomass was estimated using the volumetric method, with samples filtered through a clean net material and transferred to a measuring cylinder for displacement volume assessment. (Refer, Fig. no. 3)

Group Identification:
Samples were analyzed under a stereo microscope (LEICA S6D) for group identification. Major and minor taxa were counted, with sub-samples taken for further analysis. **Copepod Methodology:** Formalin-fixed samples were sorted, counted, and identified to genus level using published literature (Kasturirangan, 1963; Conway et al., 2003; Prusova et al., 2012).

Microzooplankton Sampling:
Microzooplankton were collected using a plankton net (mesh size 20 µm) and preserved with acid Lugol's solution (1-3%). Species classification utilized resources such as Algae Base and marine species identification portals.

6. Data Computation and Statistical Analysis:
Microzooplankton numbers were estimated using a Sedgewick Rafter counting cell. The following formula was applied for phytoplankton cells per liter:

$$N = Vn \times v$$

Where N is total phytoplankton cells per liter, n is the number of cells in 1 mL, v is the volume of the preserved sample in mL, and V is the total volume of water filtered in liters. Zooplankton volume was calculated as ml/m^3. Statistical analyses were performed using PRIMER 6 and Excel for diversity indices and correlations between environmental parameters and zooplankton metrics.

RESULTS AND DISCUSSION

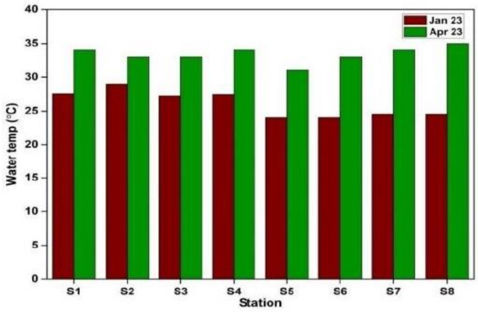
Physico-chemical parameters:

Atmospheric Temperature between S1 and S8 in January and April ranged from 25°C to 38°C. In January the temperature from S1 to S8 varied from 25°C to 35°C, whereas in April the temperature varied from 30°C to 38°C respectively. The lowest temperature was noted in January having a value of 30 °C at S6 and the highest temperature was noted during April at S1 which was 38°C.

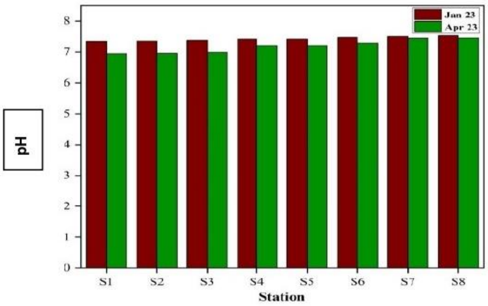
Water temperature between S1 and S8 in January and April ranged from 24°C to 35°C. In January the temperature from S1 to S8 varied from 24°C to 29°C, whereas in April the temperature varied from 31°C to 35°C respectively. The lowest temperature was noted in January having a value of 24 °C at S5 and S6 and the highest temperature was noted during January at S8.

pH range for the month of January and April was found to be varying between 7-7.5. The lowest pH i.e. 7 was observed at S1,S2 and S3 in the month of April. The highest pH was observed in the month of January i.e. 7.5 at S7 and S8 showed no variation in pH in both the months. i.e. their pH at these stations were found to be 7.5 respectively. The average pH was 7.4 and 7.1 during the months of January and April respectively.

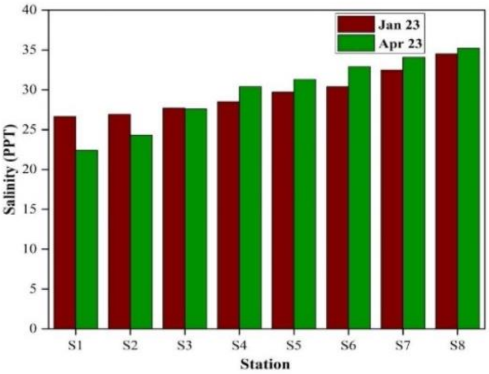
Salinity (SS) ranged from 22.40 PPT to 35.20 PPT between January and April. The average salinity in the two months ranged from 29,60 PPT to 29,77 PPT with little variation. Both months had an upward tendency, from 26.64 to 34.50 PPT and 22.40 to 35.20 PPT, respectively.



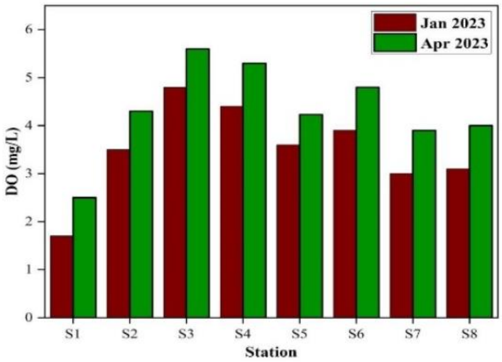
Temperature variation from S1 - S8 in Jan and April,2023



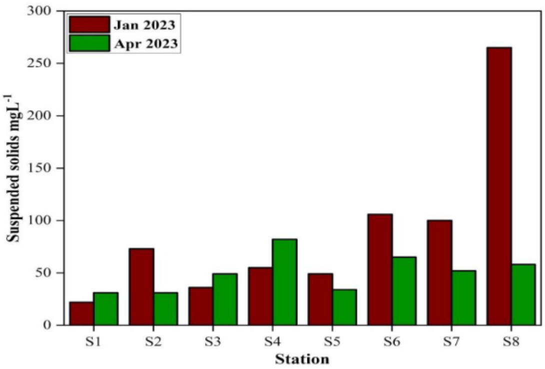
pH variation from S1 - S8 in Jan and April,2023



Salinity variation from S1 - S8 in Jan and April,2023



Dissolved oxygen variation from S1 - S8 in Jan and April,2023



Total suspended solids variation from S1 - S8 in Jan and April,2023

Figure 4: Physicochemical Parameters between S1- S8 in Jan and April

Total Suspended solids- In the current investigation, suspended solids varied from 22 to 265 mg/L between January and April. The average for January was 88.25 mg/L, while the average for April was 50.25 mg/L. As there was continual mixing of waters and diverse sources of water discharges in the stream, no distinctive patterns were noticed.

Dissolved Oxygen (DO)- In current study, DO values ranged from 1.7 mg/L to 5.6mg/L. The lowest value was recorded at S1 and highest at S3. In the January month the the values ranges from 1.7mg/L to 4.8mg/L with an average of 3.5mg/L. In April the values ranged from 2.5mg/L to 5.6mg/L with an average of 4.3mg/L. S3 and S4 collectively showed high dissolved oxygen levels in the study area.

Biological oxygen demand (BOD) for the months of January and April ranged from 1.2 mg/L to 4.9 mg/L. The lowest BOD levels at S1 were 1.2 mg/l in January and 2.1 mg/l in April. The highest BOD concentrations were 3.8 mg/l at S3 in January and 4.9 mg/l at S3 in April. Between January and April, the average BOD was 2.9 and 3.8, respectively. (Refer, Fig. no. 4).

Chlorophyll *a*: Chl-*a* (mg/m^3) varied between 2.16 and 7.17.,being the lowest and highest concentrations found during the study period. Highest concentration was observed in the uppermost part of the creek i.e. S1, S2 and S3 in January as well as April. Decreasing trend was observed as moving seawards. Lowest chl-*a* levels were observed at S6, S7, S8 for both the months. The Average concentration was 5.82-5.42 for January and April respectively. (Refer, Fig. no. 5).

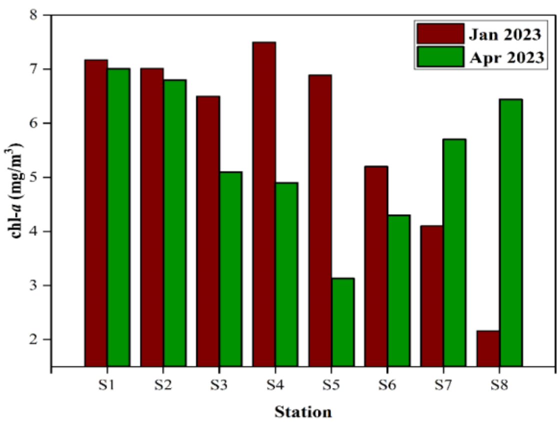


Figure 5: Variation in Chl-a concentration between S1- S8 in Jan and April

Nutrients- Nitrate: Nitrate values varied from 33.5µmolL^{-1} to 51.5µmolL^{-1} being the lowest and highest concentrations found during the study period. The lowest value was observed at S6 in January and the highest at S2 in April. The average value for January is 41.13µmolL^{-1} and for April is 43.67µmolL^{-1}**.** No significant fluctuation was observed in both the months.

Nitrite: Nitrite values ranged from 24.5µmolL^{-1} to 43.8µmolL^{-1} in January and April respectively. The lowest value recorded as 24.5µmolL^{-1} is at S6 in the month of january. The highest value was 43.8µmolL^{-1} recorded at S2 in April. The average value for January was 28.66µmolL^{-1} and for April was 38.13. The difference in values for both months is significant i.e. 9.47µmolL^{-1}.

Ammonium: The ammonium values ranged from 31.2µmolL^{-1} to 33.8µmolL^{-1} in January and April. The lowest value was observed at S5 and highest at S1. The average value for January month is 32.39µmolL^{-1} and for April is 32.64µmolL^{-1}. No significant difference was observed in both the months.

Phosphate: The average concentration of phosphate for the month of January and April was 4.10µmolL^{-1} and 6.06µmolL^{-1} respectively. The phosphate values ranged from 3.2µmolL^{-1} to 7µmolL^{-1} in January and April respectively. January Showed the lowest range i.e. 3.2-5.2µmolL^{-1} and April month showed the highest range i.e. 5.1-7µmolL^{-1}. Decreasing trend was observed toward seaward for both months.

Silicate: The concentration of Silicate varied from 10.5µmolL^{-1} to 42.3µmolL^{-1} in January and : April months. The highest concentration was seen at S1 in April and lowest at S8 in January. The average concentration for January was 29.5µmolL^{-1} and for April was 29.1µmolL^{-1}. (Refer, Fig no. 6).

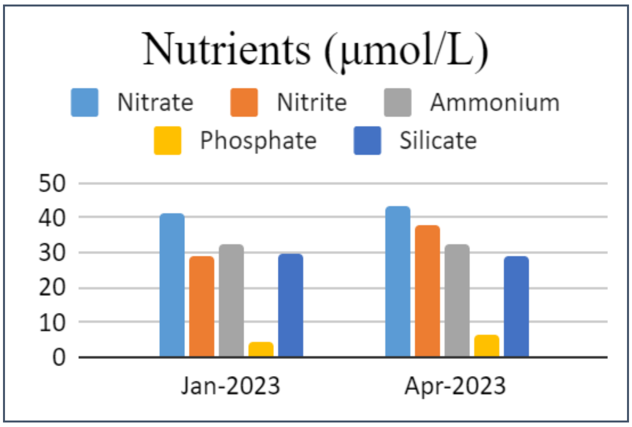


Figure 6: Variation in Nutrients concentration in Jan and April.

Zooplankton Community Analysis
Microzooplankton Diversity in Thane creek waters:

Nauplii larvae and ciliates [loricates (tintinnids) and aloricate forms] were found to be the predominant microzooplankton in the study area. During the entire study, micro metazoans such as nauplii and copepodid stages of copepods dominated the microzooplankton community followed by Ciprid, veliger and setiger larvae. Pycnogonida larvae were present only in January at S1 and S3. Rotifers were observed at S5 and S6 in January and in April at S5 and S7. Due to the shallow depth of the upper creek i.e at S1, S2 and S3 setiger larvae were abundant. Lower half of the creek i.e. S5, S6, S7 and S8 showed an increasing population. The average population for January was $11.24x10^3$ Cells L^{-1} and for April was $11.5x10^3$ Cells L^{-1}. (Refer, fig. no. 7).

Total group composition for microzooplankton in January and April Nauplii larvae and ciliates [loricates (tintinnids) and aloricate forms] were the predominant microzooplankton. During the entire study, micro metazoans such as nauplii and copepodid stages of copepods dominated the microzooplankton community. Followed by Ciprid, veliger and trochophore larvae. Pycnogonida larvae were present only in January at S1 and S3. Rotifers were observed at S5 and S6 in January and in April at S5 and S7. Due to the shallow depth of the upper creek i.e at S1,S2 and S3 trochophore larvae were abundant. Lower half of the creek i.e. S5,S6,S7 and S8 showed an increasing population. Microzooplankton abundance ranged from $4.3x10^3$ Cells L^{-1} to $22.55x10^3$ Cells L^{-1} for January and April respectively. In January, the lowest value was observed at S1 and highest was at S5. For April the lowest value was $3.85x10^3$ Cells L^{-1} observed at S1 and highest was $17.55x10^3$ Cells L^{-1} at S7.

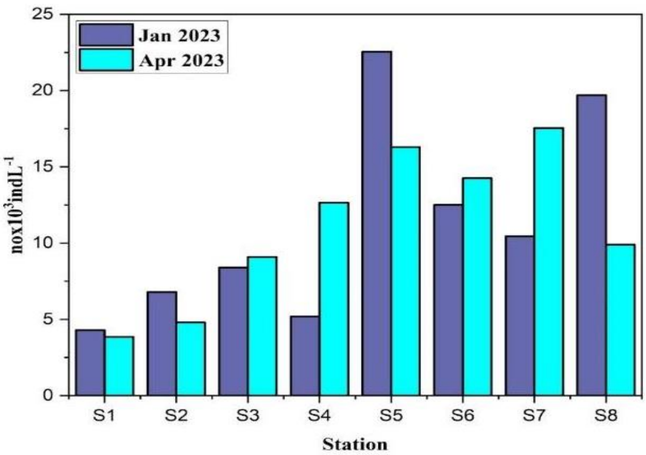


Figure no .7 Microzooplankton diversity from S1 - S8 in Jan and April

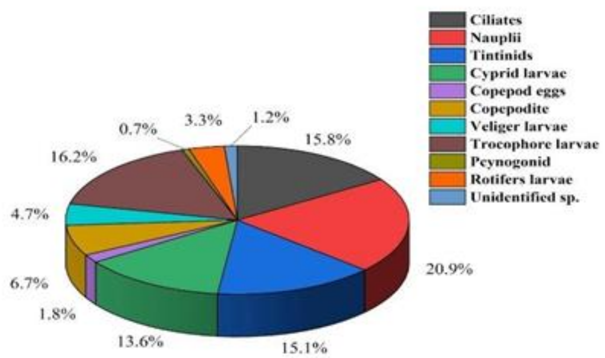


Figure 08: Percentage composition of microzooplankton in the study area during January 2023

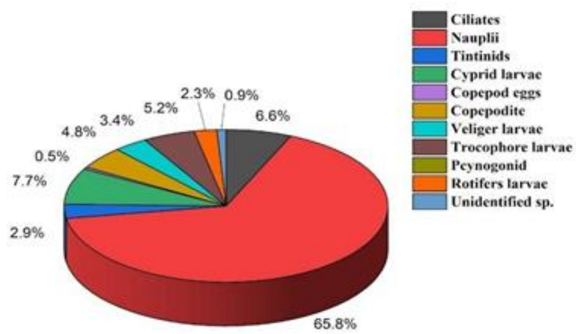


Figure 09: Percentage composition of microzooplankton in the study area during April 2023

The average population for January was 11.24x10³ Cells L⁻¹ and for April was 11.5x10³ Cells L⁻¹ The upper creek significantly shows less abundance when compared to lower creek in both the months. (Fig. 8 & 9).

Mesozooplankton Diversity in Thane creek waters:

Total Abundance and Biomass of Mesozooplankton:

The biomass of mesozooplankton was measured using the volumetric method. In January the biomass of mesozooplankton ranged from 4.2ml/100m3 to 219.4ml/100m3 and average biomass was 111.8ml/100m3. In April the biomass ranged from 5.9ml/100m3 to 54.2ml/100m3 with an average of 7.6ml/100m3. S2 showed the lowest biomass in January whereas S7 showed the highest. S5 showed the lowest biomass in April and S6 showed the highest. Spatially, the biomass was seen to be decreasing gradually as the lower half of the study area persisted with phytoplankton bloom. Zooplankton abundance ranged from 10 to 14 no x 103 /100m3 with an average of 12 no x 103 /100m3. The biomass and abundance were showing an inverse relationship in which the abundance decreases with increase in biomass. A total of 17 mesozooplankton groups were identified from the study area in January and April. Zooplankton population ranged from 43.73 ml/m3 to 3121.3 ml/m3 in January 2023 in the study area. The maximum Zooplankton population was observed at station S3 with a value of 3121.3 ml/m3 and minimum at station S2 with a value of 43.73 ml/m3. Mesozooplankton population decreased during April when compared with population in January. Spatially, the biomass was seen to be decreasing gradually as the lower half of the study area. (Refer, fig no. 10 and fig no. 11).

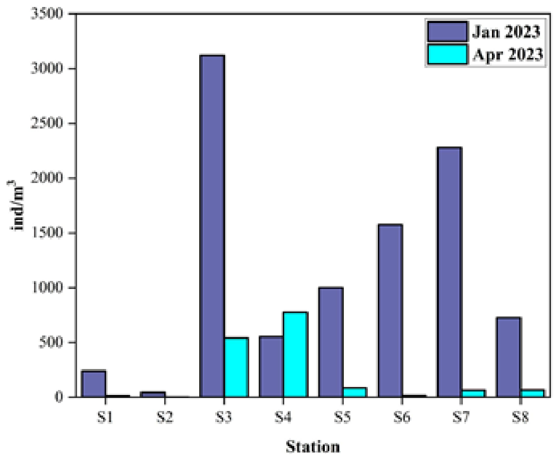


Figure 10: Mesozooplankton abundance between S1- S8 in Jan and April

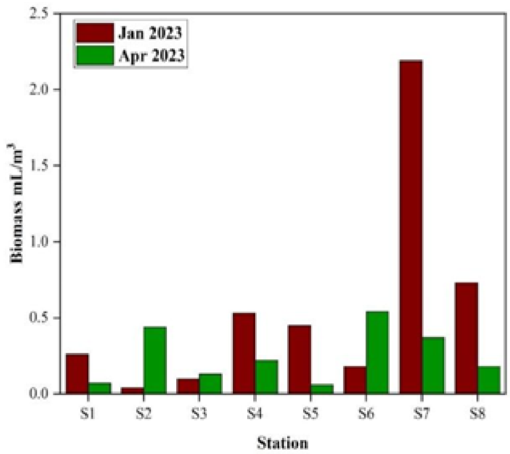


Figure 11: Mesozooplankton biomass between S1- S8 in Jan and April

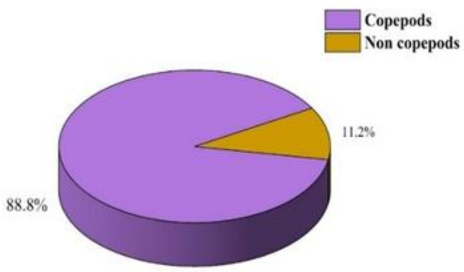


Figure 12: Percentage composition of major mesozooplankton in the study area during January 2023.

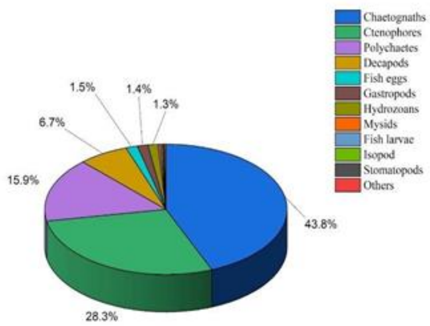


Figure 13: Percentage composition of non-copepod groups in the study area during January 2023.

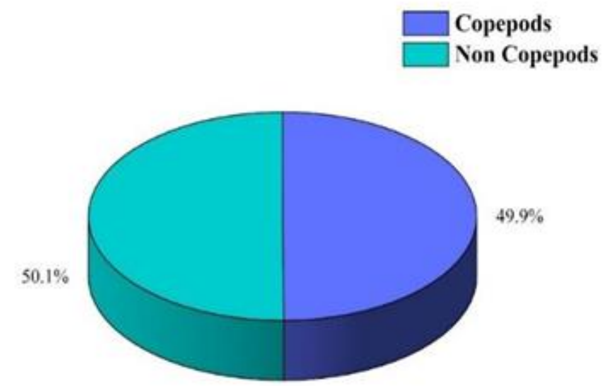


Figure 14: Percentage composition of major mesozooplankton in the study area during April 2023

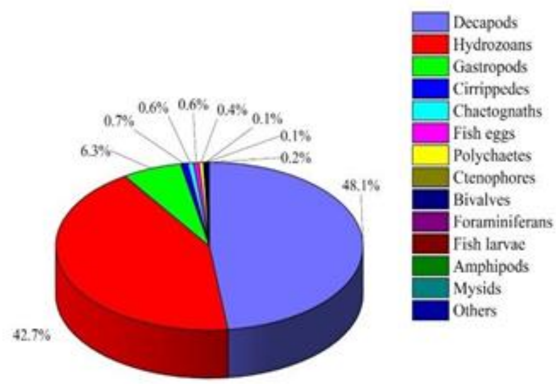


Figure 15: Percentage composition of non-copepod groups in the study area during April 2023

Spatio-temporal variation of population and total groups along the stations in January

Copepods contributed a significant share in the zooplankton composition and found to be the dominant taxa in the study area. Decapods were the second dominant group followed by hydrozoans. Copepods were present in all the stations with significant range. Contribution of fish eggs and fish larvae was very low. Hydrozoans, Ctenophores, Copepods, Chaetognaths were present at seawards i.e. at S6, S7, S8 with an increasing trend and *Acetes indicus* were observed only in January at station S6, S7 and S8. (Refer, fig no. 12 and 13).

Spatio-temporal variation of population and total groups along the stations in April

Copepods contributed a significant share in the zooplankton composition and found to be the dominant taxa in the study area. Decapods were the second dominant group followed by the hydrozoans. Copepods, Hydrozoans, Decapod larvae, were present in all the stations with significant range. Contribution of fish eggs and fish larvae was very low. Polychaetes were less observed throughout the stations (Refer, fig no. 14 and 15).

Diversity indices of Microzooplankton:

The microzooplankton diversity of the study area was calculated using PRIMER software. Species richness was measured using Margalef's richness (d). The highest richness was observed in January at S6 with d=0.85. The April month was found to be less rich in diversity when compared with January. The lowest richness was observed during the April month at S8 with d=0.22. For measuring evenness- Pielou's evenness (Ĵ) was used, the evenness during January month ranged between Ĵ= 0.59-0.91 and for April month it ranged between Ĵ= 0.31-0.86. During January highest evenness was seen at S6 (0.91). The average eveness observed for January month was Ĵ=0.77. and for April was Ĵ=0.57. For measuring diversity of the study area Shanon-Weiner $\acute{H}(\log_2)$ index was used. The highest $\acute{H}(\log_2)$ was recorded during the January month at S6 with $\acute{H}(\log_2)$ =2.00, thus this area was found to be highly diverse in January. The least diverse area was S8 in April ($\acute{H}(\log_2)$ =0.34). The average $\acute{H}(\log_2)$ for January and April were $\acute{H}(\log_2)$=1.40 and $\acute{H}(\log_2)$=0.98 respectively. Thus the microzooplankton in the study area was found to be highly diverse in January. Simpson's index (1-λ́) was also calculated and the average value for January and April months was (1-λ)´= 0.68 and (1-λ)´= 0.48 respectively. (fig no. 16)

Diversity indices of Mesozooplankton: The mesozooplankton diversity of the study area was calculated using PRIMER software. Species richness was measured using Margalef's richness (d). The highest richness was observed in April at S8 with d=2.16. The January month was found to be less rich in diversity when compared with April. The lowest richness was observed during the April month at S4 with d=0.36. For measuring evenness- Pielou's evenness (Ĵ) was used, the evenness during January month ranged between Ĵ= 0.14-0.57 and for April month it ranged between Ĵ= 0.61-0.85. During April highest evenness was seen at S2 and S7 (0.85). The average eveness observed for January month was Ĵ=0.41. and for April was Ĵ=0.76. For measuring diversity of the study area Shanon-Weiner Ḣ(log_2) index was used. The highest Ḣ(log_2) was recorded during the April month at S7 with Ḣ(log_2) =2.42, thus this area was found to be highly diverse in April. The least diverse area was S4 in January (Ḣ(log_2) =0.33). The average Ḣ(log_2) for January and April were Ḣ(log_2)=0.96 and Ḣ(log_2)=1.71 respectively. Thus the mesozooplankton in the study area was found to be highly diverse in April. Simpson's index (1-λ́) was also calculated and the average value for January and April months was (1-λ)´= 0.47 and (1-λ)´= 0.76 respectively. (Refer, fig no. 17).

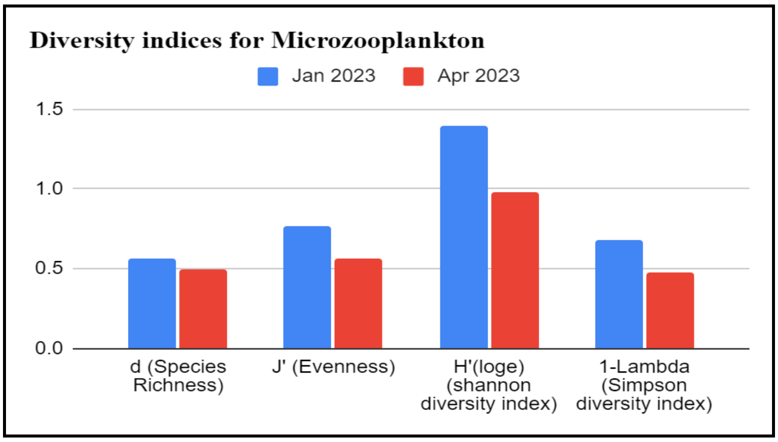


Figure no. 16. Diversity indices for Microzooplankton

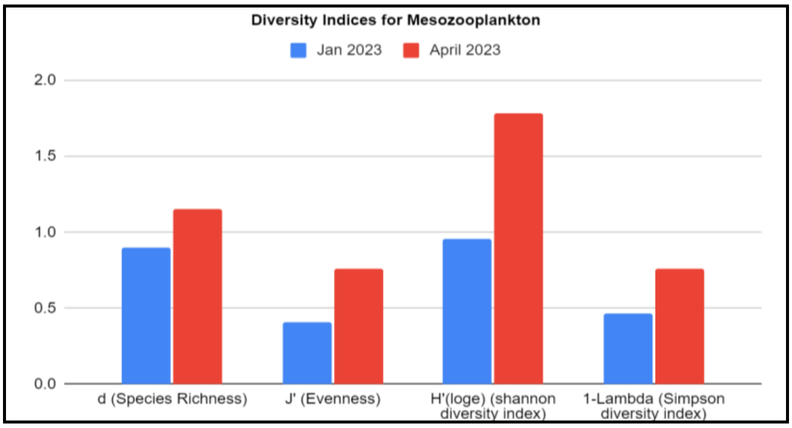
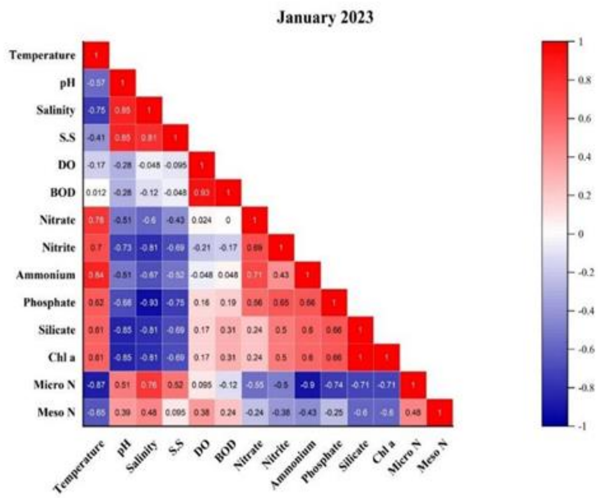


Figure no. 17. Diversity indices for Mesozooplankton



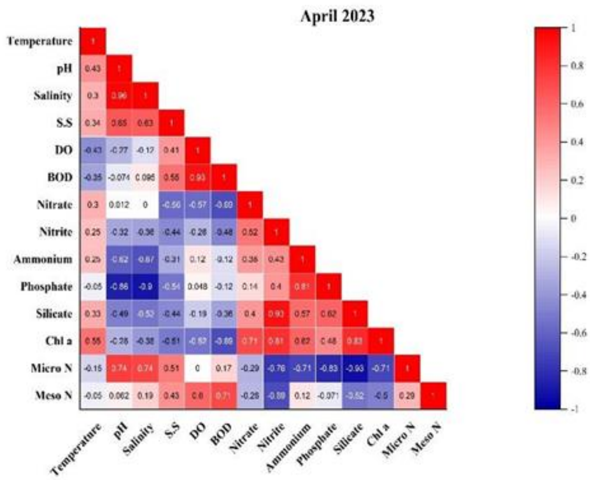


Figure 18: Spearman's correlation for January 2023

Figure 19: Spearman's **correlation for April 2023**

Statistical correlation between the plankton variables and physico-chemical parameters

In January, Salinity and microzooplankton abundance were positively correlated by (r=0.76). Although comparatively low, mesozooplankton abundance is favorably correlated with salinity by (r= 0.48), Followed by other physicochemical parameters such as pH, suspended solids and dissolved oxygen. Negative correlation is observed for zooplankton with Temperature values. For Microzooplankton values are (-0.87) and for mesozooplankton values are (-0.65). Zooplankton are showing negative correlation with nutrients such as Nitrate, Nitrite, Ammonium, Phosphate and Silicate. Also, with chlorophyll-*a*. (Refer, fig no. 18).

In April, microzooplankton abundance was positively correlated with salinity (r=0.74). Although comparatively low, mesozooplankton abundance is favorably correlated with salinity by (r=0.19), Followed by other physicochemical parameters such as pH, suspended solids and dissolved oxygen and BOD. Negative correlation is observed for zooplankton with Temperature values by (r=-0.15) and (r=-0.05) for microzooplankton and mesozooplankton respectively. Zooplanktons are showing negative correlation with nutrients such as Nitrate, Nitrite, Ammonium, Phosphate and Silicate. Also, with chlorophyll-a. (Refer, fig no. 19).

DISCUSSION

Physicochemical parameters

The spatio-temporal distribution and community structure of biota in aquatic ecosystems are predominantly influenced by varying environmental conditions and hydrographic instabilities. The present study focused on the microzooplankton and mesozooplankton community structure along Thane creek, concurrent with hydrodynamics and nutrient variability. The study was conducted over a six-month period; however, due to time constraints, sampling was carried out opportunistically in January and April, which are considered transitional months between winter and summer. This approach provided insights into seasonal variations in the zooplankton community within Thane Creek.

Temperature is one of the most important physical parameters, significantly influencing various life processes. The temperature ranged from 24°C to 35°C for both January and April, with average values of 26°C and 33.4°C, respectively. The higher temperature in April can be attributed to increased solar radiation. In contrast, during the monsoon season, temperatures were lower than in the pre-monsoon period due to heightened land runoff resulting from rainfall and breeze (Santhanam et al., 2003). A comparison of overall monthly average temperatures indicated cooler waters during the winter months (December to February) and higher temperatures in the summer (April to May) (Quadros, 2002). Tropical estuaries typically exhibit limited variation in surface temperature distribution (Vineetha et al., 2015).

The pH, which measures hydrogen ion activity in water, averaged 7.4 in January and 7.1 in April, showing negligible differences. These values were slightly higher than typical estuarine pH which is during the spring flood period (Lande, 2020).

Salinity, a critical factor for marine and estuarine biota, varies due to the interplay between evaporation, precipitation, and freshwater influx. The average salinity for January and April was 29.6 PPT and 29.8 PPT, respectively, exhibiting a spatial gradient towards the estuarine mouth—a common pattern in estuarine salinity distribution (Menon et al., 2000). The increase in surface salinity moving seaward suggests that the water column in Thane creek was well-mixed (Thomas et al., 2021).

In addition to silt, clay, agricultural waste, and inorganic and organic constituents from residential sewage and industrial effluents, phytoplankton and zooplankton are classified as total suspended solids (TSS). TSS concentrations ranged from 22 mg/L to 265 mg/L. This loading contributes to increased turbidity, which reduces the depth of the photic zone and subsequently decreases primary production. The observed variability suggests continuous mixing of waters from diverse discharge sources, resulting in a lack of distinct patterns in TSS distribution.

Dissolved oxygen (DO) is essential for the survival of aquatic flora and fauna. Respiratory processes consume DO, while photosynthesis adds oxygen to the water. Active photosynthesis and respiration of planktonic organisms can cause significant fluctuations in oxygen concentration over short periods. Decomposing bacteria can rapidly deplete oxygen from the waters (Levinton, 1982). According to Adeney (1908), bacterial decomposition can lead to anoxic conditions in aquatic ecosystems. DO deficiency, often used as an indicator of deteriorated water quality, has been widely documented in estuarine and coastal waters (Park et al., 1996). In Thane creek, DO values below 2.5 mg/L were considered hypoxic (Quadros, 1995) and were observed in the upper stations of the study area. Anoxic conditions were not detected during the study period; however, previous studies reported anoxia in various Indian waters, including Ashtamudi estuary, Kadinamakulam Kayal, and Malad creek (Nair & Abdul Aziz, 1997; Nadan & Abdul Aziz, 1990; Alam, 1992). Alam (1992) noted higher DO levels in Malad creek at the seaward end compared to the riverine end, attributing this to differences in sewage load.

When DO levels are insufficient for biological needs, biochemical oxygen demand (BOD) increases. BOD measures the dissolved oxygen required by aerobic microorganisms to break down organic matter at a given temperature. Throughout all stations, BOD levels were high, with upper stations showing higher oxygen demand compared to lower stations. Additionally, Cold water retains oxygen better than warmer water, so in summer months, dissolved oxygen is usually lower from the start. The sampling months being January and April could also be the reason for lower dissolved oxygen.

Nutrient variability can be linked to various anthropogenic activities, including the disposal of domestic and industrial wastes. Key elements such as nitrogen, phosphorus, and silicon are essential for phytoplankton growth, and fluctuations in these nutrients can affect their diversity and distribution. Nitrate levels exhibited minimal variation between seasons, with a difference of 2.54 µmolL-1; however, nitrite levels were higher in April compared to January by 9.47 µmolL-1. Nitrate was the predominant nutrient in Thane creek during both January and April, with high concentrations attributed to increased waste discharge and photosynthetic organisms in the post-monsoon season, mirroring observations made by Segar and Hariharan (1989). Elevated nitrate and nitrite concentrations can lead to eutrophication, resulting in hypoxic or even anoxic conditions for other organisms. Studies by Sawant (2007) in Mumbai and Jawaharlal Nehru Port highlighted the rising nutrient levels, particularly nitrate, in Thane creek over the years. Ammonia concentrations were higher during pre-monsoon and monsoon seasons, averaging 6.5 µmolL-1 and 6.34 µmolL-1, respectively. Upper creek areas showed elevated levels during the monsoon, linked to increased organic matter and the death of photosynthetic organisms (Segar and Hariharan, 1989). In this study, average ammonium levels were 32.39 µmolL-1 and 32.64 µmolL-1. Phosphate concentrations averaged 4.10 µmolL-1 in January and 6.06 µmolL-1 in April, with the highest levels in the upper half of the creek, likely due to increased sewage discharge and land runoff. This has led to the development of an eutrophied zone along the Kopri-Vitawa to Vikhroli-Koparkhairane gradient. Silica, an important algal nutrient, has received less attention in estuarine nutrient over-enrichment studies compared to nitrogen and phosphorus, despite its significance (Malone et al., 1996). The study area, influenced by various discharges from Mumbai, can significantly alter water quality (Govindan, 2000; Vijay et al., 2014; NIO, 2018). Previous studies on Thane creek by Ramaiah (1997) indicated that industrial and domestic waste influenced water quality, potentially leading to lethal and sublethal effects. Quadros (2001) also noted the deteriorating condition of Thane creek due to increasing pollution.

Phytoplankton biomass was estimated using chlorophyll-*a* concentration, which exhibited remarkable spatio-temporal variation throughout the study area. The average chlorophyll-*a* values in this study aligned with those reported by Karati et al. (2021), showing a positive correlation with silica and temperature.

Micro and Mesozooplankton:

Zooplankton species composition and seasonal variations significantly influence the productivity and fisheries potential of estuarine environments (Sastry and Chandramohan, 1995). Zooplankton play a crucial role in aquatic ecosystems, impacting nutrient dynamics and food web structures (Raphael et al., 2009). Thane Creek serves as a vital fishing site for various fish and crustacean species.

Microzooplankton, ranging from 20–200 µm, include heterotrophic microplankton such as protozoans and metazoans (Porter et al., 1985). The average microzooplankton abundance in this study was 1013.5 Cells L^{-1}, comparable to the range observed in the Zuari estuary (90 – 1130 Cells L^{-1}) (Elangovan and Gauns, 2021).

Table no. 3: Zooplankton Density and Biomass from Various Water Bodies

Density (no/100 m^3)	Biomass (mg/m^3)	Water Bodies	References
1396	350	Cochin Backwater	Madhupratap & Haridas (1975)
1690	9	Ambica Estuary	Nair et al. (1981)
2746	8	Auranga Estuary	Nair et al. (1981)
1297	8	Mindola Estuary	Nair et al. (1981)
1315	7	Purna Estuary	Nair et al. (1981)
55	0.007	Bukki Creek	Gajbhiye et al. (1981)
102	0.021	Dahej Creek	Gajbhiye et al. (1981)
126926	30.21	Dharamtar Creek	Tiwari (1990)
27918	2.984	Thane Creek	Quadros (2001)

Copepod nauplii contributed significantly (20.9% in January and 65.8% in April), efficiently feeding on various prey sizes from nano- to micro-zooplankton (Rodrigo et al., 2011; Uye and Kasahara, 1983), potentially explaining the lower microzooplankton abundance in the area. The reduced numbers of aloricate ciliates may result from grazing pressure by metazoan predators and limited availability of nanoplankton (Gomez, 2007; Booth et al., 1993). Challenges in sampling and identifying small, delicate aloricate ciliates often lead to their underrepresentation in routine quantifications. Microzooplankton abundance showed a positive correlation with salinity (r = 0.76 and 0.74), supporting Gauns' (2000) findings that MZP abundance in the Zuari estuary is influenced by both food availability and optimal salinity conditions (~15–20 psu).

The zooplankton community is sensitive to environmental changes, responding to factors like nutrient loading and fish densities (Beenamma & Yamakanamardi, 2011; Pace, 1986; Canfield & Jones, 1996). Changes in physicochemical parameters can significantly alter the composition and abundance of aquatic organisms, making zooplankton valuable indicators for monitoring aquatic systems (Shivashankar & Venkataramana, 2013; Jose et al., 2015). The variability in zooplankton community structure contributes to the observed paradox in biomass and abundance distribution. Mesozooplankton biomass ranged from 0.25 to 0.56 ml/100 m^3, consistent with other Indian estuaries (Table 5A).

According to Nair et al. (1983), polluted areas around Bombay sustain high zooplankton biomass due to gelatinous organisms. Thane Creek's high suspended solids may also influence biomass. Temporal and spatial distribution of zooplankton is driven by environmental factors, competition, predation, and random events (Soetaert & Rijswijk, 1993). Higher biomass at select stations is likely due to increased gelatinous zooplankton, including hydrozoans, ctenophores, and chaetognaths. Mesozooplankton abundance was positively correlated with salinity during the post-monsoon season. A total of 31 zooplankton taxa were identified, categorized into those occurring throughout the creek, those influenced by salinity gradients, and those with sporadic occurrences. For example, Clytia sp., Oithona sp., Paracalanus sp., and Acartia sp. were consistently found, while Pleurobrachia sp. and Sagitta sp. were influenced by salinity. Sporadic taxa included Ostracods, Spionid sp., and Neomysis.

Community structure is essential for plankton dynamics and reflects trophic structure and energy flow (Giering et al., 2019). Copepods dominated across both the months, Carnivorous mesozooplankton, such as chaetognaths, were more abundant in the upper study segments, indicating a preference for higher salinity environments (Nair, 1971; Junior et al., 2019). Nair (1971) noted that chaetognaths are more abundant in macro-tidal estuaries, correlating with findings from Karati et al. (2021), who reported higher hydromedusae occurrences in pre-monsoon seasons. Seasonal surface temperature variations also influence hydromedusae abundance, as seen in the current study. Padmavati and Goswami (1996) and Menon et al. have suggested that estuarine zooplankton community dynamics are primarily driven by salinity variations both spatially and temporally.

SUMMARY AND CONCLUSION

Zooplanktons are recognized as a valuable indicator of environmental health and ecosystem functioning. Decadal change in the Zooplankton data can provide valuable insights on impacts of climate change on aquatic ecosystems. The purpose of the thesis is to examine the impact of physicochemical variables on the dynamics of zooplankton in the anthropogenically susceptible Thane Creek, west coast of India. The microzooplankton study reveals nauplii larvae as the dominant group in January and April with 21% and 66% occurrence respectively. Most nauplii stages are omnivorous, feeding predominantly on phytoplankton and microzooplankton and others are carnivorous, feeding predominantly on other zooplankton including copepods. This may have caused depletion of other nanoplankton and microzooplankton groups like tintinnids. No much variation in microzooplankton abundance was observed however diversity varied for January and April.

A total of 31 taxa belonging to 18 mesozooplankton groups were identified from the study area. The mean biomass and abundance of mesozooplankton were highest in January 2023 and relatively low in April 2023 in the Thane creek. Copepods dominated the January and April trials, forming a large group. Genus level identification showed that *Oithona* sp. were prevalent in both months. It can have several reasons; its size is 0.2-1 mm long, it has a flexible feeding behavior, can withstand extreme conditions and has a high reproductive capacity. The densities of zooplankton of Thane creek are high compared with other indian estuaries indicating fishing potential of the creek irrespective of the pollution load. The major Zooplankton groups such as copepod, chaetognaths, polychaete, hydrozoans, decapod, *Acetes* sp. make most of the biomass. This shows decadal change in the mesozooplankton composition recorded by (Quadros 2001). Zooplankton abundance showed negative correlation with the nutrients values which indicates high availability of nutrients depleting zooplankton assemblages.

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