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Assessment of suitability of a rejuvenated creek in the urban area for cage aquaculture using multi-criteria decision support analysis - A case study from south-east coast of India

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Abstract

This study assessed the suitability of rejuvenated Adyar Creek in Chennai, Tamil Nadu, South India to develop cage culture based on the seasonal changes in physico-chemical water quality parameters *viz.,* pH, dissolved oxygen (DO), salinity, total alkalinity, total hardness, nutrients, metabolites as well as diversity of flora and fauna. The entire area of the creek was found most suitable for cage culture in terms of pH, nitrite, nitrate and phosphate during all seasons. However, the overall suitability assessment found that 65.8 and 27% of the creek area were found most suitable and suitable, respectively. The DO level was lower than optimum in the inlet areas of drainage water and away from the bar mouth. Such sites need to be either avoided for cage culture, or the sandbar of the river needs to be maintained, ensuring smooth water exchange between the estuary and the sea, to safeguard water suitability thoughout the year. This study established the areas feasible for cage culture in the rejuvenated Adyar Creek, based on water quality. This would in turn help to support the local communities and government to strategise and productively utilise brackishwater resources to improve the livelihood of the people inhabiting areas around the creek.

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Introduction

Aquaculture has been growing exponentially with the ever-increasing demand for protein-rich food coupled with stagnating production from capture fisheries. Brackishwater, with its rich biodiversity, offer an excellent opportunity for aquaculture. Brackishwater is the confluence of fresh and seawater in the estuarine zone and various sectors compete for space in the limited coastal resource availability (Jayanthi *et al.,* 2021). Cage culture in brackishwater areas could be an attractive alternative for the livelihood of the local community.

The Adyar Creek in Chennai lost its pristine condition in the late 20th century due to urban development, discharge of untreated sewage and industrial effluents; solid waste disposal as well as encroachments, leading to. loss of many of its key attributes, such as floral and faunal diversity, and its role as a spawning and nursery ground of commercially significant finfish and shellfish species (Janakiraman *et al.,* 2017). To restore the ecology of the Adyar Creek, the Govt. of Tamil Nadu has initiated the Chennai Rivers Restoration Trust (CRRT). The sludge accumulated over the years was removed by the trust, resulting in an increase of water spread in the creek, in addition to protecting the water body from external pollution sources.

Unlike marine cage culture, brackishwater aquaculture in the estuarine zones has its own challenges, especially near cities and towns owing to pollution from various sources, closure of bar mouth in different seasons, inadequate water depth, high turbidity and mainly, low water quality

(Scharler *et al.,* 2020). Hence, it is of utmost importance to carefully select the site which fulfils the key requirements for brackishwater cage culture. Geographical Information System (GIS) and remote sensing assist in providing an integrated pictorial view of the key environmental parameters and aquatic biota to support site selection (Meaden and Aguilar-Manjarrez, 2013). The current study strives to evaluate the spatial and temporal patterns of water characteristics, plankton abundance and diversity in Adyar Creek, Chennai, Tamil Nadu, to identify suitable sites for cage aquaculture.

Materials and methods

Study area

The Adyar Creek is located in the southern part of Chennai, Tamil Nadu, at latitude 13°01'N, longitude 80°16'E along the south-east coast of India.

Sampling details

To assess the potential for cage culture in the Adyar Creek, water samples were collected at different points in the creek (Fig. 1) for two years at monthly intervals and analysed for vital parameters. Simultaneously, the spatial and temporal pattern of distribution of phytoplankton and zooplankton were also studied in the selected sites. The study period was divided into winter (January-February), summer (March-May); South-west monsoon (SWM: June-September); North-east monsoon (NEM: October-December).

Water samples were collected from the selected sites in 500 ml sampling bottles for the analysis of key physico-chemical parameters, nutrients and metabolites. Water samples collected at the subsurface level for phytoplankton were fixed with 1% Lugol's iodine solution on the spot for further analysis. Phytoplankton identification was done to species level and counting was performed using a haemocytometer. Zooplankton samples were collected using a plankton net (60 µ mesh size) and preserved with 4% formalin solution for further studies. The counting was carried out using the Sedgewick rafter counting chamber and zooplankton were identified up to generic level by microscopic observation.

Water quality parameters

The water quality parameters *viz.*, pH, salinity, temperature and dissolved oxygen, were measured directly in the field using portable meters. Temperature and dissolved oxygen were determined using an optical dissolved oxygen meter (YSI Pro ODO, Yellow Spring Instruments, Ohio, USA). pH and salinity were measured by pH meter and refractometer, respectively. Total hardness and alkalinity were determined as described in APHA (2017). Water nutrient parameters (nitrate-N, reactive phosphorus) and metabolites (total ammonia-N and nitrite-N) were analysed by standard methods (Strickland and Parsons, 1972).

Estimation of plankton abundance and diversity

Plymouth Routine in Multivariate Ecological Research (PRIMER 7) software was used to analyse biological properties such as Abundance (N), number of species (S), Pielou evenness index (J), Shannon Wiener diversity index (H'), Margalef richness index and Simpson domination index (λ).

Spatial analysis

The cloud-free Sentinel 2B data of Adyar Creek with tile number T44PMV dated 27 March 2019 has been used to delineate the boundary of the study region. The satellite data pre-processing and subsetting were done using ERDAS Imagine. The image was projected to the Universal Transverse Mercator Zone 44N and then the creek area of the present study was mapped using visual interpretation techniques in ArcGIS 10.6.

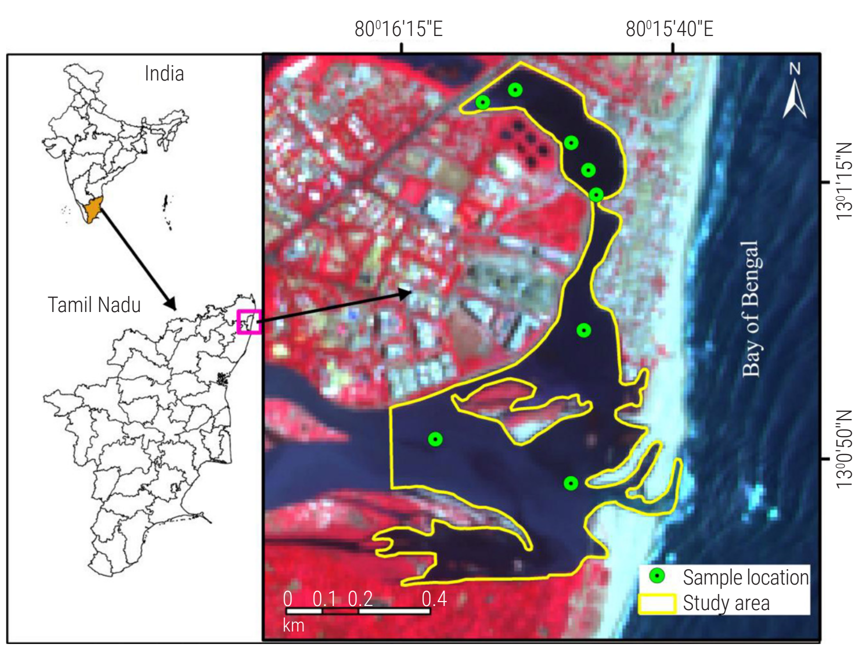


Fig. 1. Map of Adyar Creek with sampling points

The measured water quality parameters of Adyar Creek in the selected regions and the geographic coordinates of sampling points were used for interpolation of season-wise creek parameters using the Inverse Distance Weighted interpolation method. The interpolated maps were reclassified into different levels and the extent of the region at each suitability level was calculated based on the suitability of water characteristics for cage aquaculture indicated in Table 1 (Saraswathy *et al.,* 2015; Jayanthi *et al.,* 2021).

Results and discussion

Assessment of water quality parameters

pH

The water pH varied from 7.62-8.31; 7.39-8.8; 7.65-8.98; 7.29-8.4 for winter, summer, SWM and NEM, respectively. The mean creek water pH varied between 8.02 and 8.31 among the seasons and the values were within the optimum range in all four seasons, not causing risk to fish (Fig. 2). Aquatic animals inhabiting the estuary are exposed to a varied range of pH values and it depends on the variations in the seawater, discharge and tidal flow. The average seawater pH value ranged between 7.63 and 8.15. The value of pH reduces gradually due to the rise in atmospheric carbon-di-oxide, which dissolves in water forming carbonic acid (Boyd, 2020).

Salinity

The salinity of creek water ranged between 22-27; 15-35, 4-26 and 2-28 ppt for winter, summer, SWM and NEM, respectively. Estuarine salinities generally change due to run-off of freshwater from land caused either by monsoon or tidal variations. In the present study, the mean salinity was high during summer (27.2 ppt) and low during SWM (11.83 ppt). This variation is caused by monsoon and tidal variations, and it is reflected in the values of seawater, with the highest value of 32.7 ppt recorded in summer and the lowest value of 11.3 ppt in SWM (Fig. 3). Brackishwater fish species have the unique ability to withstand a wide range of salinities and the salinity range between 15 and 30 ppt is suitable for cage culture (Rao *et al.,* 2013). These species balance salinity variation in the estuary through the expenditure of metabolic energy (Soengas *et al.,* 2008). Studies have shown that oxygen consumption decreases with a salinity reduction, by 10 ppt while an increase of 30 ppt salinity enhances the oxygen intake of the animal (Sutton *et al.,* 2018). Salinities within the optimal range facilitate proper osmoregulation and promote growth of the animals.

Temperature

The mean temperature recorded in the creek varied between 27.4 and 32.6°C with the annual lowest and highest values of 25.9

Table 1. Range of water quality parameters for cage culture in Adyar Creek

Parameters	Suitability range		
	Most suitable	Suitable	Not suitable
Temperature (°C)	27-31	25-26; 32-38	>38: <25
pH	7-8.5	6.5-6.9; 8.6-9.5	>9.5; <6.5
Salinity (ppt)	20-30	10-19; 31-35	>35; <10
DO (mg l^{-1})	≥5	4-4.9	<4
Total alkalinity (ppm as $CaCO_3$)	50-150	150-400	<20; >400
TAN (mg l^{-1})	0-2	2.1-4	>4
Nitrite-N (mg l^{-1})	0-0.05	0.06-0.2	>0.2
Nitrate (mg l^{-1})	≤3	3.1-10	>10
Phosphate (mg l^{-1})	0.01-2	2.1-3	>3
Turbidity (NTU)	10-27	28-35; <10	>35

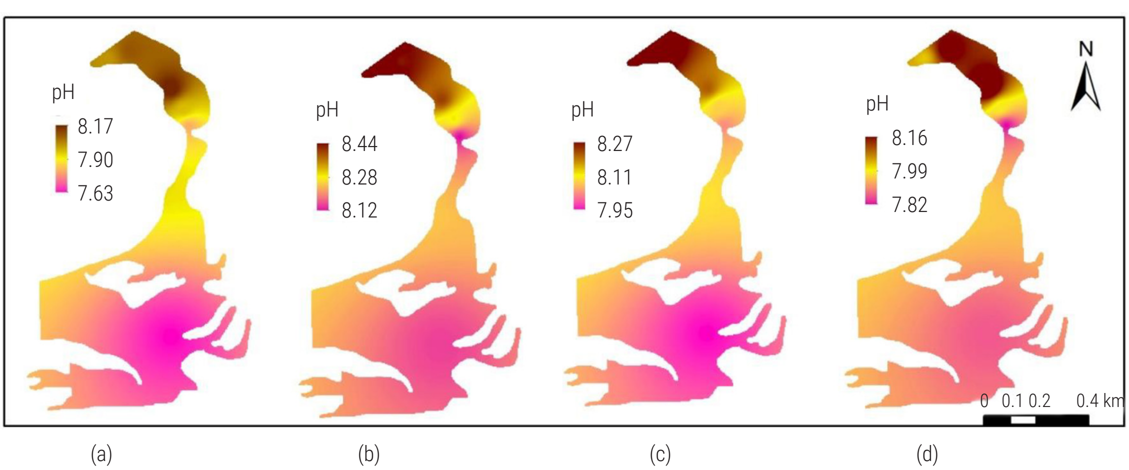


Fig. 2. Map depicting seasonal changes in water pH. (a) Winter; (b). Summer; (c) SWM and (d) NEM

and 35.3°C in winter and summer, respectively (Fig. 4). Although the optimum temperature range for culturing fish is between 22 and 35°C (Tucker *et al.,* 2002), the thermal acceptance level for fish ranges from 15 to 40°C. Temperatures below or at about 20-22°C affects the growth of animals (Mackinnon, 1989) and above the optimal range causes stress that could adversely affect the immune function of fish (Dominguez *et al.,* 2004), making the fish susceptible to diseases (Matanza and Osotio, 2018).

Fish requires gradual acclimatisation when moving from one environment to another as temperature shocks cause higher stress and eventually, mortality of fish. The tolerance level is around 0.2°C per minute provided the total change in temperature does not exceed a few degrees (Boyd, 1990). The animal's metabolic activity and growth rate are lower during winter when the low temperature has a chilling effect. However, warmer water is more critical as it is unable to hold as much dissolved oxygen as cooler water. The fluctuation in growth is lower when the temperature is more stable (A'yun and Takarina, 2017).

Dissolved oxygen

Dissolved oxygen is the regulator of the metabolic activities of organisms and a good indicator of the trophic status of the water body. The mean of seasonal dissolved oxygen content varied from 3.7 to 4.38 mg l^{-1} throughout the study period (Fig. 5). In the creek, DO values are around 58% lower than in seawater, which ranged between 6 to 6.8 ppm due to the presence of aquatic animals and plankton. Shallow water estuaries experience good water mixing due to wind-generated tides, which in turn increases oxygenation and reduces anoxia triggered by eutrophication, which may be harmful to numerous organisms (Kjerfve and Magill, 1989; Powers *et al.,* 2005).

Nutrient concentration

The mean nitrate concentration in the Adyar Creek ranged from 0.163 to 1.219 mg l^{-1} and the highest value of 1.83 mg l^{-1} was recorded during the SWM, which is well within the permissible limits. The nitrate level in the receiving stream tends to increase through leaching and surface runoff (Rao, 2011), but nitrate is relatively non-toxic to fish except at exceedingly high levels of more than 90 mg l^{-1} (Moniruzzaman *et al.,* 2015). According to Boyd (1998), the desired concentration is 0.2 to 10 mg l^{-1}, whereas Furnas (1992) indicated that concentration from 0 to 200 ppm are acceptable for fish culture. The toxic concentration of nitrate is higher than the metabolites ammonia and nitrite (Lawson, 1995).

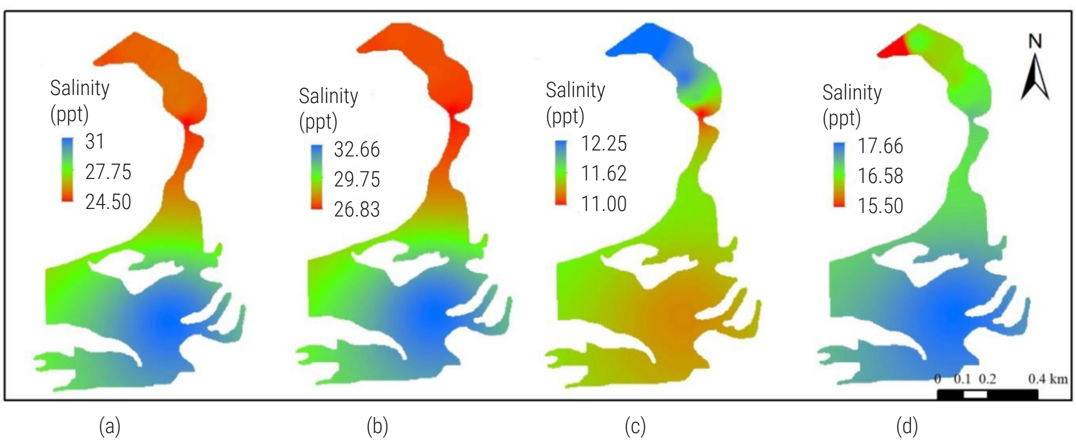


Fig. 3. Seasonal influence on water salinity in Adyar Creek. (a) Winter; (b) Summer; (c) SWM and (d) NEM

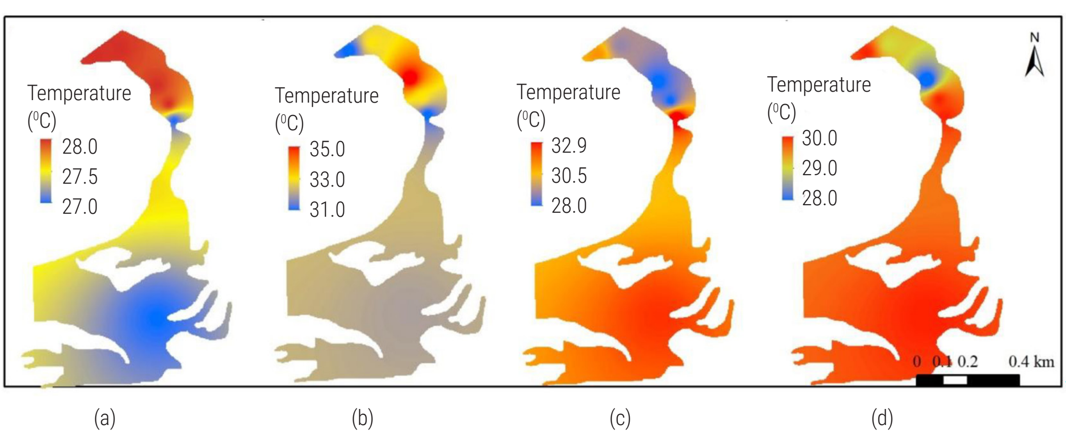
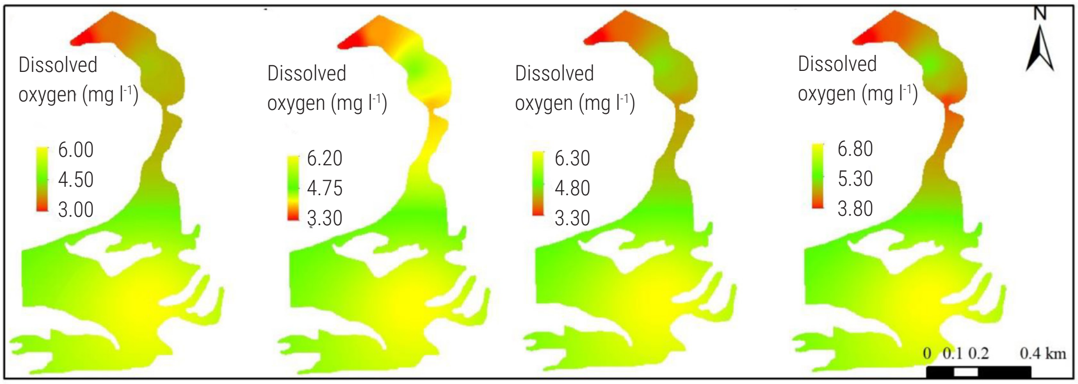


Fig. 4. Seasonal variation in temperature of Adyar Creek. (a)Winter; (b) Summer; (c) SWM and (d) NEM



(a) (b) (c) (d)

Fig. 5. Changes in dissolved oxygen concentration in Adyar Creek at different seasons. (a) Winter; (b) Summer; (c) SWM and (d) NEM

Phosphate is another vital nutrient which plays a limiting factor in the maintenance of estuarine fertility. The seasonal mean phosphate values in the Adyar Creek ranged between 0.376 and 1.107 mg l^{-1} (Fig. 6), within the desirable limit of 3 mg l^{-1} (Jayanthi *et al.,* 2021). There is a high positive correlation between phosphate and phytoplankton abundance (Saraswathy *et al.,* 2012). Phosphate concentration above the desirable limit causes algal bloom, which results in the reduction of oxygen level.

Variations in metabolites concentration

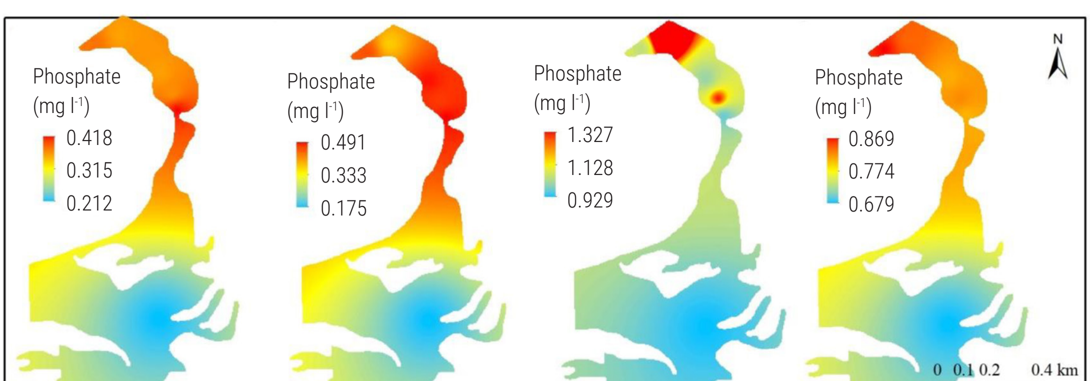
Ammonia is the primary nitrogenous waste excreted by fish from protein digestion, and it was higher during fish culture (Nyanti *et al.,* 2012; Yee *et al.,* 2012). The mean TAN values ranged from 1.3 to 1.698 and the metabolite concentration highly depends on the tidal pattern. A high concentration of TAN during monsoon periods indicates a higher level of pollution due to the accumulation of domestic sewage in the water body during rainfall. During this period, a higher concentration of ammonia was recorded in seawater as well ranging between 3.64 and 4.31 ppm in SWM and NEM, respectively (Fig. 7). Karnatak and Kumar (2014) reported that ammonia nitrogen increases in and around the cage when there is no water movement through the cage. It highly influences the dissolved oxygen concentration in water since oxidation of 1 mg ammonia requires 4.6 mg oxygen. Boyd (2001) reported that ammonia concentration between 3 and 4 mg l^{-1} may be lethal for tropical fish. Ammonia concentration in cage culture systems varied between 0.01 to 1.15 mg l^{-1} (Eglal *et al.,* 2009).

Nitrite concentration in the Adyar Creek ranged between 0.043 and 0.219 mg l^{-1} (Fig. 8), which is within the desirable limit of 0.3 mg l^{-1} (Boyd, 1998) and suitable for the culture of fish (milkfish). Moniruzzaman *et al.* (2015) suggested that the desirable range of NO_2 is 0-1 mg l^{-1} and the acceptable range is less than 4 mg l^{-1} NO_2. The bacteria *Nitrosomonas* converts ammonia into nitrite. Each 1 mg l^{-1} of total ammonia nitrogen can get converted to 3 mg l^{-1} of nitrite in a short duration (Durborow *et al.,* 1997).

Both ammonia and nitrite are toxic to fish. The level of metabolite toxicity varies with fish species and environmental parameters such as water temperature, pH and chloride concentration of water. Sublethal levels of ammonia cause damage to the gill and tissue, leading to poor growth and susceptibility to disease. Similarly, nitrite at sublethal levels reduces oxygen transport into the fish, resulting in poor feed conversion, reduced growth and increased susceptibility to diseases (Masser, 1968).

Plankton

Study of phyto and zooplankton composition, abundance and seasonal variation is helpful in successful fisheries and aquaculture management (Kiran *et al.,* 2007).



(a) (b) (c) (d)

Fig. 6. Phosphate concentration in Adyar Creek across the seasons. (a) Winter; (b) Summer; (c) SWM; (d) NEM

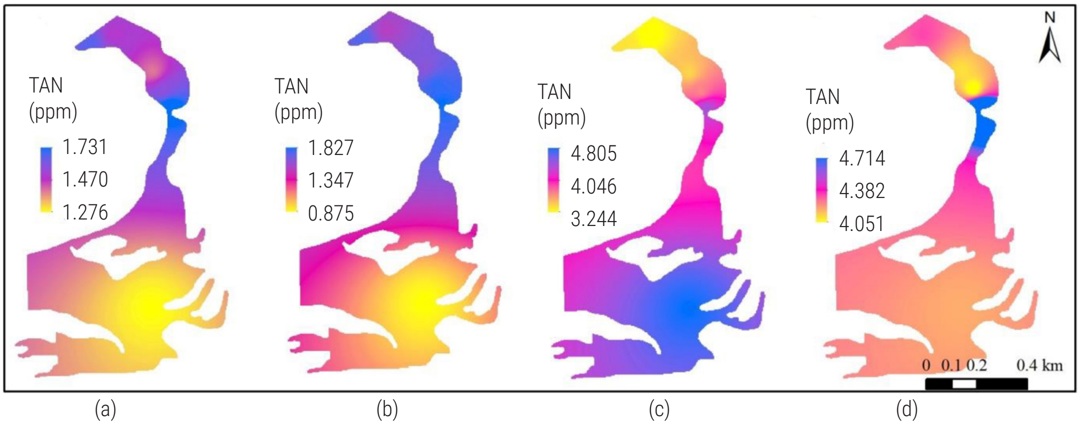


Fig. 7. Influence of seasons on TAN concentration in Adyar Creek. (a). Winter; (b) Summer; (c) SWM and (d) NEM

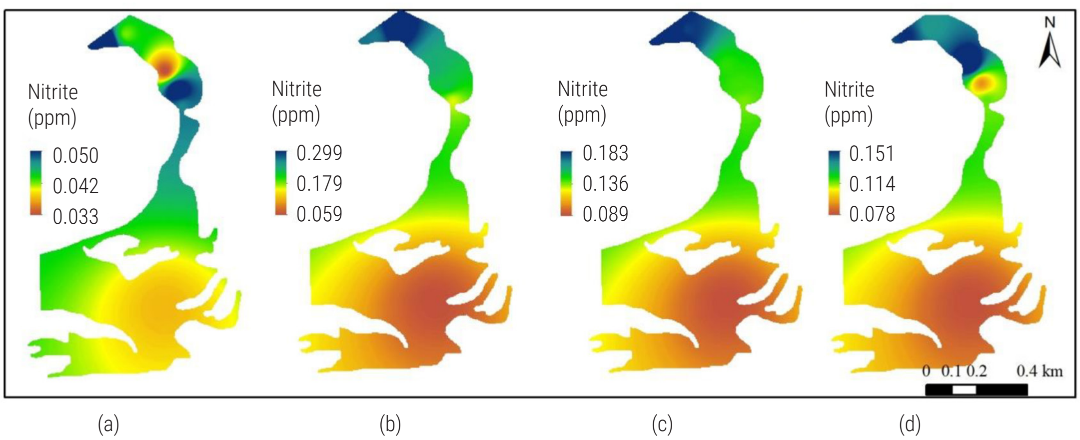


Fig. 8. Nitrite concentration in Adyar Creek at different periods. (a). Winter; (b) Summer; (c) SWM and (d) NEM

Phytoplankton abundance

During the course of the study, 22 species of phytoplankton were identified from 5 taxonomic groups. Bacillariophyceae was the dominant group (69.6%) with 16 species followed by Chlorophyceae (Fig. 9). The temporal pattern in the abundance of taxonomic groups of phytoplankton (Fig. 10a) indicates dominance of Bacillariophyceae during south-west monsoon (44.6%) followed by NEM (32%), summer (17.1%) and winter (6.3%) (Fig. 10a). Season-wise phytoplankton diversity indicates the dominance of Bacillariophyceae (86.9%), followed by Chlorophyceae (12.4%) in winter. A similar trend was observed in SWM and NEM. The density of Bacillariophyceae was probably influenced by lower temperatures during the winter and monsoon periods and the mixing pattern. In summer, the dominance of Bacillariophyceae is followed by Euglena and Chlorophyceae (Fig. 10b).

Among Bacillariophyceae and Chlorophyceae, *Chaetoceros* sp. and *Chlorella* sp. dominated all seasons, respectively. Phytoplankton under the class Cyanophyceae, *Oscillatoria* sp. and *Spirulina* sp. were identified during the study period. The highest degree of similarity in phytoplankton abundance was observed during the North-east and South-west monsoon (89.2%) followed by summer and winter (69.5%). Chlorophyceae, Cyanobacteria and Bacillariophyceae were the dominant influencers of zooplankton development. The occurrence of *Euglena* spp. bloom during the summer season, along with direct organic pollution in all stations, suggests the influence of domestic waste entering the ecosystem due to tidal influence. According to Hosmani (2013), *Euglena* spp. serve as biological indicator of pollution in the aquatic ecosystem.

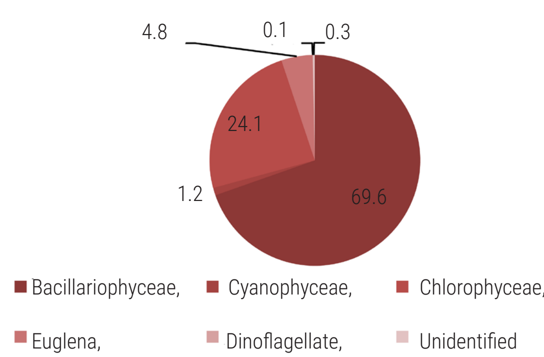
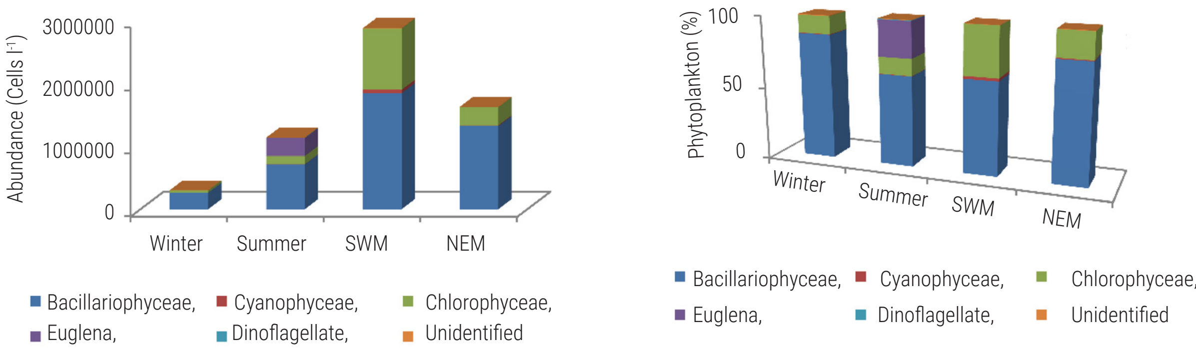


Fig. 9. Abundance of various groups of phytoplankton in Adyar Creek



(a) (b)

Fig. 10. Seasonal influence on the abundance of phytoplankton. (a) Abundance (Cells l^{-1}); (b) Phytoplankton taxonomic group distribution (%) in each season

Phytoplankton diversity indices

Primer analysis depicts the diversity indices, which include Margalef's richness (d), Pielou's evenness index (J^1), Shannon-Weiner diversity [H'(loge)] and Simpson diversity. The analysis revealed the pattern of diversity during different seasons, and their corresponding values ranged between 0.417-0.714, 0.649-0.751, 0.900-1.346 and 0.499-0.689, respectively (Fig. 11). Integrated usage diversity indices are fit for analysing the phytoplankton community (Morris *et al.,* 2014). The Simpsons index accounts for the number of species present and the abundance of species. Greater value of Simpson index was observed during summer (0.714), which indicates greater species diversity and less diversity was observed during monsoon and winter periods (Fig. 11). In tropical estuaries, phytoplankton biomass decreases during the monsoon period due to monsoon driven seasonal discharge pattern and freshwater inputs due to rainfall (Sarma *et al.,* 2009).

Zooplankton abundance and diversity in Adyar Creek

Among zooplankton species, rotifers and copepod dominated throughout the season and the maximum cumulative abundance of zooplankton species was observed during NEM followed by SWM (Fig. 12). Temporal pattern of zooplankton showed the dominance of rotifers in the NEM followed by SWM, summer and winter (Fig. 13a). Season-wise zooplankton diversity indicates the dominance of rotifer (55.2%), followed by copepods (41%) in winter. A similar trend was observed in all the seasons. *Moina* sp. was observed only in the monsoon seasons (Fig. 13b). The maximum abundance of zooplankton observed during monsoon seasons could be attributed to beneficial microalgae abundance, particularly diatoms and Chlorophyceae in all the stations. The presence of Cladocera particularly *Moina* sp, during NE and SW monsoons may be attributed to the higher occurrence of Chlorophyceae compared to the rest of the season. Optimal temperature conditions and the availability of phytoplankton as a food source further contribute to the increased density of Cladocera (Amar *et al.,* 2012).

Adequate zooplankton density is critical for the growth and survival of larvae of many fish species, eventually influencing the abundance of adults (Houde, 1987). The survival of fish larvae is dictated by the quantities, timing and suitability of planktonic species (Durant *et al.,* 2005; Payne *et al.,* 2009) and changes in the planktonic community (Beaugrand *et al.,* 2003).

Zooplankton diversity indices

Shannon Weiner index value varied between 1.46 and 1.78 and was observed to be maximum during NE monsoon followed by SW monsoon, winter and summer. No significant difference was observed in the diversity indices between the seasons. The highest values of Shannon Weiner's diversity index indicate the presence of favourable environmental conditions and an abundance of food sources for zooplankton (Fig. 14).

Characteristics of the creek site

The key considerations for the selection of an appropriate site for cage culture include water depth, distance from the bar mouth and water turbidity. The study site was located at a distance of around 2 km from the bar mouth and water depth varied between 2.48 and 4.6 m. The water depth varied during the high tide and low tide between 3.4 to 5.5 m and 1.9 to 4 m respectively. A minimum water depth of 2 m at low tide time is required for cage culture as reported by Tookwinas and Charearnrid (1988). The site for cage culture in the Adyar Creek should be selected based on optimal water depth, ensuring that the cage bottom remains free from the substrate during low tide and is easily accessible. The seasonal mean water turbidity ranged between 9.8 and 21.2 NTU, falling

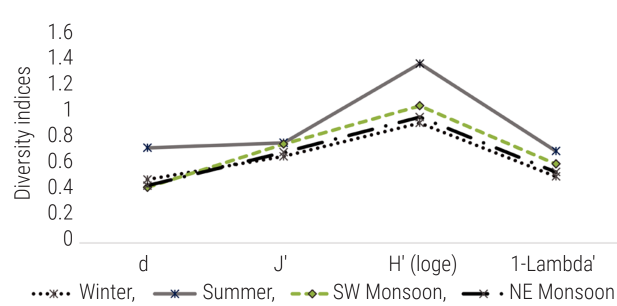


Fig. 11. Phytoplankton diversity indices in Adyar Creek during the study period

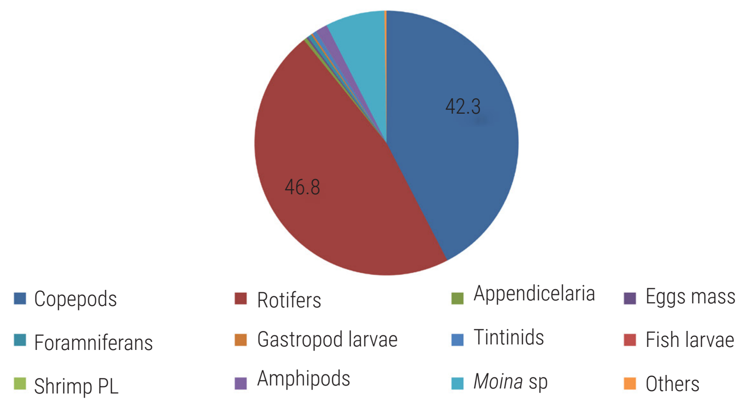


Fig. 12. Abundance of zooplankton species in Adyar Creek

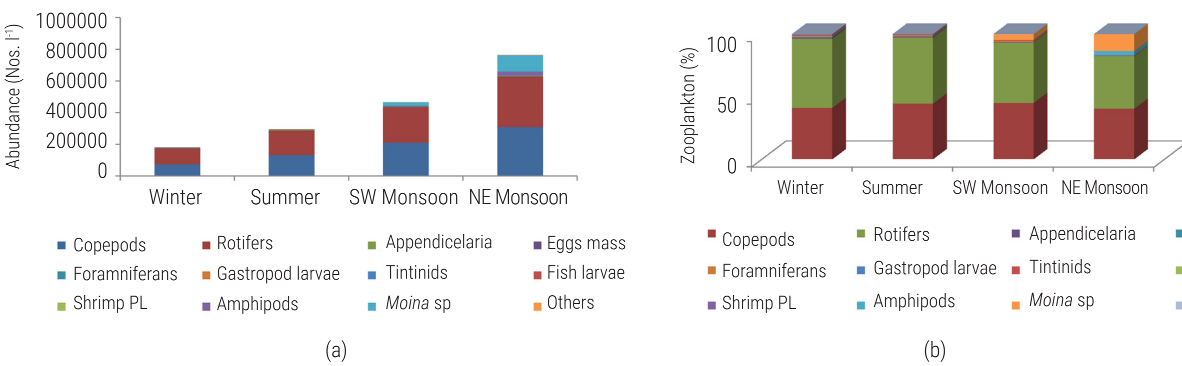


Fig. 13. Seasonal influence on the abundance of zooplankton. (a) Abundance (Cells l^{-1}), (b) Distribution of zooplankton (%) in each season

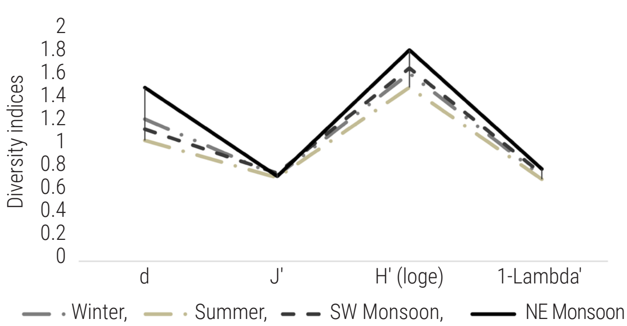


Fig. 14. Zooplankton diversity indices in Adyar Creek during the study period

within the acceptable limits for cage culture (Jayanthi *et al.*, 2021). The highest turbidity levels (16-25.5 NTU) were recorded during the south-west monsoon likely due to runoff. In other seasons, turbidity levels were lower, attributed to higher water flushing rates.

Characterisation of spatial variability of creek water characteristics

The entire extent of the creek area has been classified as most suitable, suitable and unsuitable for cage culture based on the vital water characteristics collected during different seasons. The entire creek was found most suitable for cage culture in terms of pH, nitrite, nitrate and phosphate in all four seasons. The lagoon area of 67700 (16.5%), 20800 (5.1 %), 23200 (5.7%) and 5500 sq.m (1.3%) had low DO of <4 ppm during winter, summer, SWM and NEM respectively. Based on the overall suitability assessment, 65.8% of the creek area was classified as most suitable, while 27% of the area classified as suitable (Table 2). In small pockets where drainage water enters and in areas away from the bar mouth, the dissolved oxygen concentration ranged from from 3.0-3.8 ppm. These sites should be avoided for cage culture.

During monsoon seasons, TAN concentrations exceeded the optimum level, likely due to rainwater carrying sewage and drainage water into the Adyar Creek. To mitigate pollution, sewage from illegal settlements should be redirected to the pumping station near the Foreshore Estate bus terminus, helping to reduce pollution levels and improve conditions for aquaculture. In addition to this, harvesting before the monsoon period can minimise risks associated with pollution levels.

This study assessed the suitability of the Adyar Creek to develop cage aquaculture by assessing resource quality and availability. The spatial variability of the physical characteristics of the creek, along with its diverse flora and fauna, makes the creek highly suitable for fish culture. The primary objective of the study is to improve the livelihoods of the communities living near the Adyar creek through

Table 2. Assessment of brackishwater suitability extent in Adyar Creek

Parameters	Extent of suitability (m^2)			Percentage		
	Most suitable	Suitable	Not suitable	Most suitable	Suitable	Not suitable
Temperature (°C)	847300	792700	0	51.7	48.3	0
pH	1640000	0	0	100	0	0
Salinity (%)	490000	1150000	0	29.9	70.1	0
DO (mg l^{-1})	1079400	443400	117200	65.8	27	7.2
Total alkalinity (ppm as $CaCO_3$)	180000	1050000	410000	11	64	25
TAN (mg l^{-1})	80000	740000	820000	4.9	45.1	50
Nitrite-N (mg l^{-1})	0	1640000	0	0	100	0
Nitrate (mg l^{-1})	1640000	0	0	100	0	0
Phosphate (mg l^{-1})	1640000	0	0	100	0	0

cage culture, adopting a family farming approach. This model has the potential to be replicated in other urban estuarine water bodies. Additionally, the establishment of habitats will help maintain the estuary in a clean and pristine condition.

Acknowledgements

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