

Original Research

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Diversity of *Ceratium* Schrank (Dinophyceae) species in the surface waters of Dhamra, Odisha, Eastern India

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Abstract

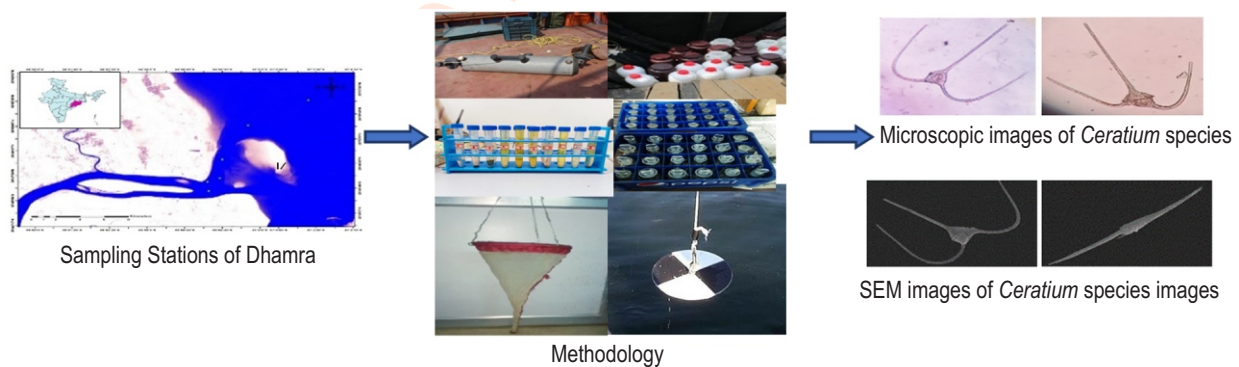
Aim: To study the diversity of *Ceratium* Schrank (Dinophyceae) species in the surface waters of Dhamra, Odisha, Eastern India.

Methodology: The present study was carried out at six GPS coordinated stations in the coastal waters of Dhamra, Odisha during pre-monsoon, monsoon and post-monsoon periods (March 2021, October 2021 and February 2022). Standard methods were followed for measuring sea surface temperature, transparency, dissolved oxygen, pH, alkalinity, salinity, silicate, nitrite, nitrate and phosphate. Samples were collected by filtration as well as towing method. Light microscopy and scanning electron microscopy were carried out for the identification of *Ceratium* species.

Results: A total of twenty-eight species of *Ceratium* were observed. Out of the reported twenty-eight species, *C. massiliense* var. *armatum* and *C. breve* var. *breve* have not been reported earlier in the coastal waters of Dhamra, Odisha. Diversity of *Ceratium* species was influenced by various parameters. Analyses of water quality parameters, showed that the transparency, salinity, alkalinity, nitrite and phosphate were maximum during pre-monsoon whereas temperature and silicate concentration were higher in monsoon. Similarly, during post-monsoon, pH and nitrate concentration were maximum. Availability of nutrients might have probably influenced the distribution of *Ceratium* species in the coastal waters and one of the sources was from the riverine influx.

Interpretation: Abundance of *Ceratium* species is probably regulated by alkalinity, high transparency, salinity and phosphate concentration in the surrounding water. Dhamra coastal water is conducive for the growth of *Ceratium* sp. which primarily uses phosphate for developing the horns.

Key words: Abundance plot, Bray-Curtis, *Ceratium*, Dinophyceae, Species diversity



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Introduction

Phytoplanktons are microscopic floating plants that convert inorganic compounds to organic compounds which are the main source of marine primary productivity. Their photosynthetic activity involves the uptake of carbon dioxide and release oxygen required for respiration by other living organisms (Japa *et al.*, 2021). They play a major role in carbon and nutrient cycling, energy flow, and production of food sources for different trophic levels. Distribution, abundance, and growth rate of phytoplankton mainly depend on the biotic and abiotic factors and they respond quickly to the presence of any stress or change in their environment. Hence, they act as an excellent indicator of pollution and water quality. Productivity and abundance of plankton depend on the physico-chemical parameters and nutrient availability (Kumar *et al.*, 2022; Cavalcante *et al.*, 2016). Dinoflagellates are microscopic acellular algae which can swim as cells, thrive under non-conducive climatic conditions and participate in vertical migration (Hackett *et al.*, 2004).

Dinoflagellates are characterized by the presence of a girdle (the groove that separates the two halves of the cell) and sulcus (perpendicular groove of the cell) with the flagella originating from the perpendicular groove, *i.e.*, sulcus (Mahoney, 1978). *Ceratium* sp. varies between 20-200 μm and has specific number of plates arranged throughout and marine species have around four plates (Meave *et al.*, 2003). A single apical horn and two antapical horns are attached to the cell body. The apical horn may be straight or slightly curved. Antapical horns may be present in different patterns. The cell body of *Ceratium* sp. is made up of two distinct halves: the epitheca (upper) and the hypotheca (lower). The epitheca and hypotheca are separated by a groove called girdle. The ventral side of hypotheca has a vertical cavity called sulcus. In most cases, *Ceratium* possess 3 horns, one horn in the epitheca and two horns in the hypotheca. Based on the shape of horns and cell body, *Ceratium* sp. are grouped into 4 subgenera, *i.e.*, *Amphiceratium*, *Biceratium*, *Tripoceratium* and *Archaeoceratium* (Okolodkov, 2010). Antapical horns are absent in subgenus *Archaeoceratium*. In *Biceratium*, antapical horns are more or less equal in length. Antapical horns are posteriorly directed or recurved anteriorly in the subgenera *Tripoceratium*. In *Amphiceratium* subgenera right antapical horn is reduced or absent whereas the left antapical horn is highly elongated.

Ceratium species can form bloom, leading to oxygen deficiency which may be harmful to the fish and other coastal fauna (Cavalcante *et al.*, 2016). Macedo *et al.* (2021) observed that the broad range of morphometric variation in *Ceratium* species is adapted due to changes in the environmental parameters, especially water temperature. Few *Ceratium* species form blooms (red tides) which may decrease the nutrient concentration in the surrounding water and adversely affect the marine ecosystem as well as human health (Severiano *et al.*, 2022; Hasani *et al.*, 2022). Generally, toxic and non-toxic blooms are formed by *Ceratium* species and it might affect the oxygen uptake phenomenon. The blooms formed by *Ceratium* species

decrease the quality of water and block the gills of fish and shellfish. A significant increase in algal bloom has been observed in both estuarine and marine water causing a serious threat to the health of the aquatic ecosystem (Edoa *et al.*, 2022). Few invasive species of *Ceratium* like *Ceratium furcoides* are capable of destroying the biota during its bloom formation due to the availability of high nutrients and low zooplankton grazing (Pacheco *et al.*, 2021). *Ceratium* species are good competitors to other phytoplankton groups as they are capable of vertical migration and are good swimmers (Cavalcante *et al.*, 2016). Optimum temperature regulates their cell size and population density (Tambaru, 2022).

Larger cell size has been observed during winters as compared to summer season whereas, population density increases during warmer conditions (Cavalcante *et al.*, 2016). In the present study, *Ceratium* species was selected for the study over other dinoflagellates as they are good indicators of increase in temperature and warm waters. With the increase in temperature *Ceratium* species move to deeper layers to counteract the impact of increase in temperature. further, the growth rate of *Ceratium* species is highest between pH 7.5 to 8.0 and growth rate of *Ceratium lineatum* reduces at higher pH (Hansen, 2002). Baek *et al.* (2008) observed that the cell density of *Ceratium furca* and *C. fusus* were increased along with nitrate concentration. Cavalcante *et al.* (2016) observed higher bloom of *C. furcoides* in Brazilian alkaline freshwater and our results are on similar lines wherein growth of *Ceratium* species has bloomed under alkaline conditions. In view of the above, this study was conducted to investigate the diversity of dinoflagellates, especially *Ceratium* species in the surface waters of Dhamra and determine correlation between nutrients and diversity.

Materials and Methods

The present study was carried out at six sites (20°46'477" N and 86°57'727" E to 20°51'512" N and 87°02'454" E) of Dhamra, Odisha, East Coast of India during pre-monsoon, monsoon, and post-monsoon periods in the year 2021-2022 (Fig. 1). Confluence of River Brahmani and Baitarani forms dhamra river and it releases water into the Bay of Bengal. Dhamra river mouth is closer to Gahirmatha sanctuary and Bhattarkanika which is the nesting place of Olive-ridley and rich biodiversity site of estuarine crocodiles. Surface water samples were collected with the help of a Niskin water sampler at GPS-fixed sampling sites. For the analysis of dissolved oxygen, water samples were fixed in BOD bottles following Winkler's method (Strickland and Parsons, 1972). The remaining samples were transferred into the ice box to the laboratory. The samples were analyzed as per the standard methods (Strickland and Parsons, 1972). Air and water temperature were measured with a 0.01°C precision thermometer. pH was measured with a micro-processor pH meter (Metzer-2001M Model) and transparency was measured with the help of a Secchi disc.

For estimating salinity, refractometer was used at the sampling site and was revalidated by argentometric method in the laboratory. Nutrients like silicate (silico-molybdate method),

nitrite, and nitrate (Cadmium column method) were analysed following the procedures of Strickland and Parsons (1972). For plankton collection and counting, approximately, 30 l of water was filtered through a plankton net of mesh size 25 μm . The samples were transferred with the help of a brush into 10 ml Borosil sample collection containers. Plankton samples were preserved in 4% formalin. The samples were centrifuged at 1000 rpm for 5 min and brought to a concentrated form and were again transferred into the collection tubes. After preservation, 8 to 10 drops of 2% Lugol's Iodine was added to the sample bottles and kept at room temperature. Plankton counting was done by Sedgwick-Rafter counting chamber and for observation, one drop of the sample along with one drop of DPX (mounting medium) was taken on a slide followed by a rectangular cover slip (18 \times 18 mm) for permanent slide preparation. Prepared slides were observed under a compound microscope (Magnus MLX-TR Plus 15M0842) with 10x eyepiece and a 40x objective having 400 magnification by using fixed microscope adopter camera FMA050. Microphotographs of the observed planktons were taken with the help of a camera which was connected to the microscope through an adapter and identified using standard monographs (Gourret, 1883; Gran, 1902; Jorgensen, 1905 and 1911; Pavillard, 1907) NIO Identification manual. For scanning electron microscopy photographs, one milliliter of the concentrated sample was taken and allowed to dry on the cover slip overnight. After complete drying, the cover slip was placed over a double-sided adhesive carbon tape on the aluminium stub, followed by plasma coating and thereafter, examined under a Scanning Electron Microscope (Gemini SEM 300, Zeiss). Data were analysed using PAST(version 3.04) and BioDiversity Pro software.

Results and Discussion

Hydrological parameters: The present investigation was carried out during pre-monsoon (March-May), monsoon (June-September), and post-monsoon (October-December) seasons. The minimum sea surface temperature during pre-monsoon, monsoon and post-monsoon was 26, 31.2 and 25 $^{\circ}\text{C}$, while the maximum was 28 $^{\circ}\text{C}$, 33 $^{\circ}\text{C}$ and 28 $^{\circ}\text{C}$ respectively. The minimum transparency observed during pre-monsoon, monsoon, and post-monsoon season of 0.25, 0.15, 0.65 m and the maximum transparency ranged between 1.47, 0.9 and 0.9 m respectively. The minimum salinity observed during pre-monsoon, monsoon, and post-monsoon ranged between 17.12, 0.53 and 14.86 PSU, while the maximum values ranged between 29.46, 21.76, and 26.54 PSU, respectively. The minimum pH during pre-monsoon monsoon, and post-monsoon season was 8.15, 7.71, 8.14 while the maximum pH was 8.26, 8.23, and 8.29. The minimum DO during pre-monsoon, monsoon, and post-monsoon season was 6.4, 6.8, 5.1 mg l^{-1} while the maximum DO values was 7.2, 7.6, 5.8 mg l^{-1} , respectively. The minimum alkalinity during pre-monsoon, monsoon, and post-monsoon was 116, 60, 82 mg l^{-1} and the maximum alkalinity was 126, 102 and 90 mg l^{-1} , respectively. The minimum silicate concentration during pre-monsoon, monsoon, and post-monsoon season was 0.026, 0.101, 0.032 mg l^{-1} and the maximum silicate content was 0.055, 0.816 and 0.074 mg l^{-1} , respectively. The minimum nitrite level during pre-monsoon, monsoon, and post-monsoon season was 0.034, 0.013, 0.038 mg l^{-1} and the maximum nitrite level was 0.061, 0.042 and 0.011 mg l^{-1} , respectively. The minimum nitrate level during pre-monsoon, monsoon, and post-monsoon was 0.441, 0.209, 0.315

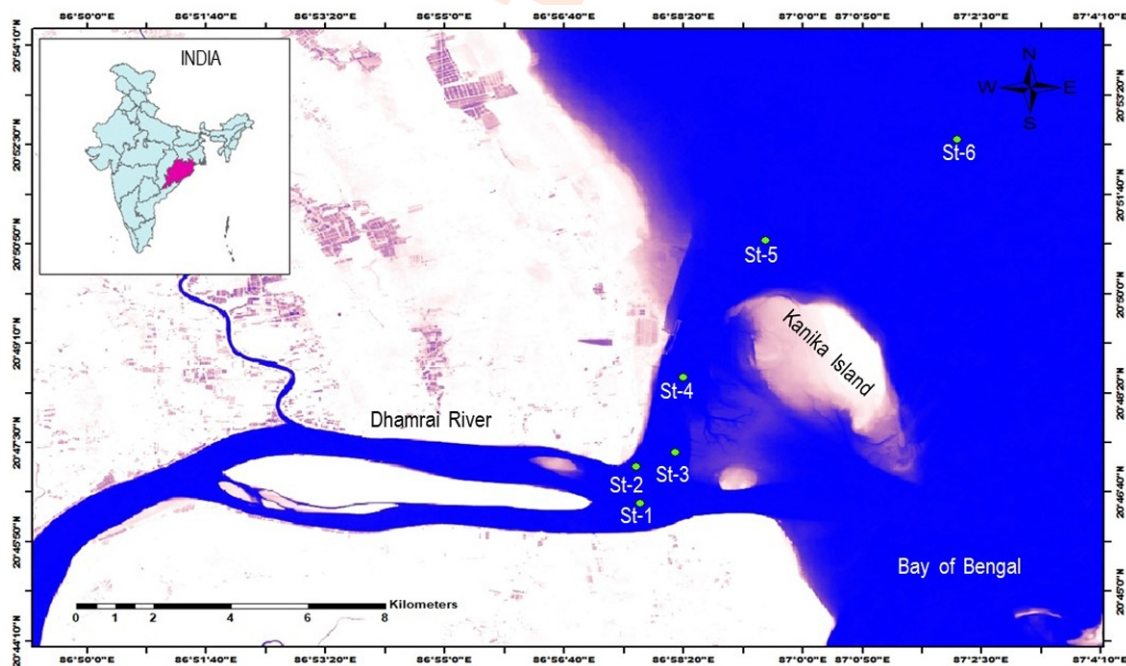


Fig. 1: Sampling sites of Dhamra (Map prepared in ArcGIS software 10.8.2).

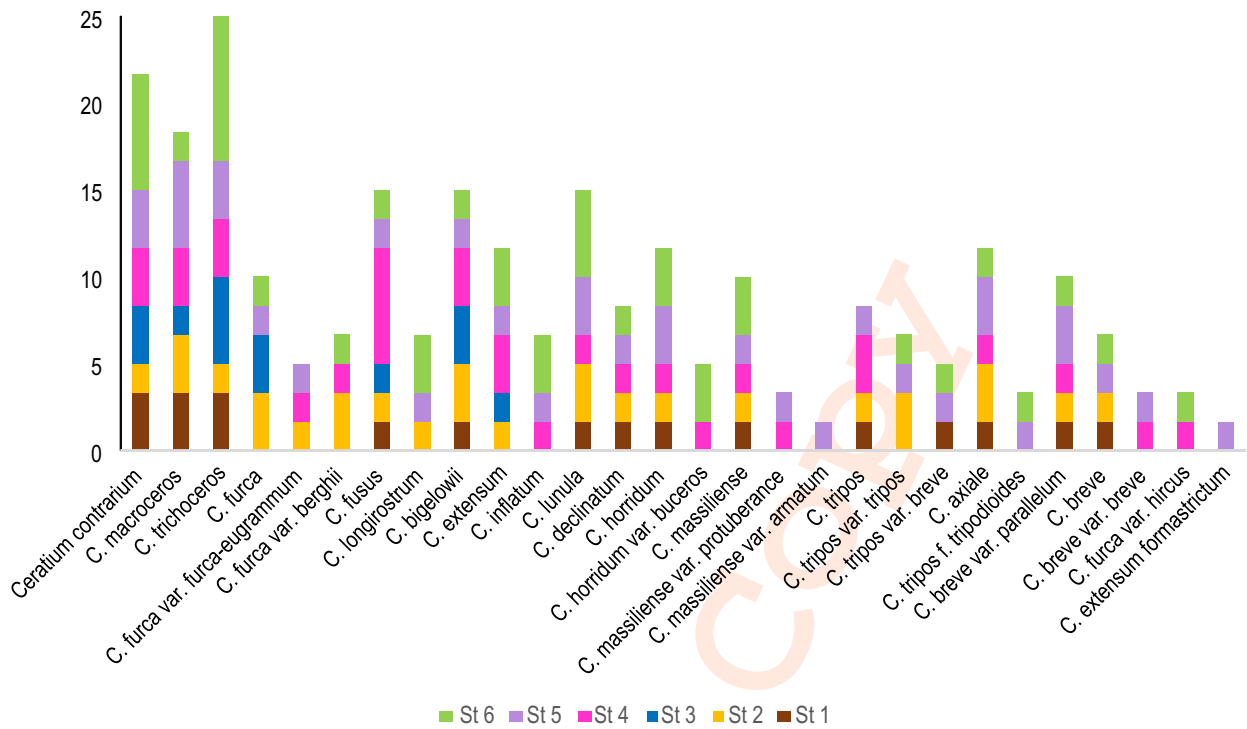


Fig. 2: *Ceratium* species distribution (per 10 ml) at different stations.

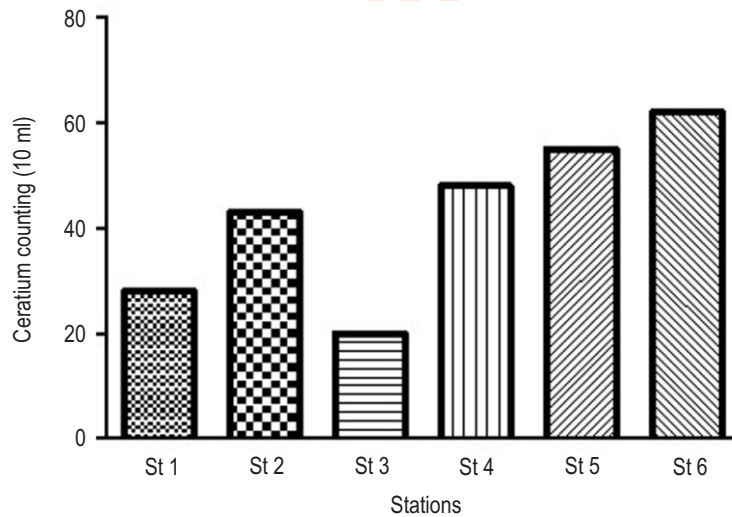


Fig. 3: Station-wise *Ceratium* cell counting.

mg l⁻¹ and the maximum nitrate level was 0.773, 0.326 and 1.109 mg l⁻¹, respectively. The minimum phosphate concentration during pre-monsoon, monsoon and post-monsoon season was 0.427, 0.061, 0.487 μM l⁻¹ while the maximum phosphate concentration was 1.211, 0.178, and 0.701 μM l⁻¹, respectively. Physico-chemical parameters along with nutrients also showed seasonal fluctuation.

Distribution: A total of 28 *Ceratium* species were identified from different sites, and the maximum number of *Ceratium* species were recorded at Station 6, followed by Station 5, Station 4, Station 2, Station 1 and Station 3. (Fig. 3). Distribution of *C. trichoceros* was highest followed by *C. contrarium* and *C. macroceros* whereas *C. massiliense var. armatum* and *C. extensum formastrictum* were lowest in number (Fig. 2). The

taxonomical identification of *Ceratium* is based on the morphology of cell body (girdle, sulcus, and horns), number of horns, and the orientation of horns. The prominent *Ceratium* species observed in the coastal waters were *Ceratium contrarium* (Gourret); *Ceratium macroceros* (Ehrenberg); *Ceratium trichoceros* (Ehrenberg); *Ceratium furca* (Ehrenberg); *Ceratium furca* var. *furca-eugrammum* (Ehrenb.) J. Schiller); *Ceratium furca* var. *berghii*; *Ceratium fusus* (Ehrenberg); *Ceratium longirostrum* (Gourret); *Ceratium bigelowii* (Kofoid); *Ceratium extensum* (Gourret); *Ceratium inflatum* (Kofoid); *Ceratium lunula* (Schimper ex Karsten); *Ceratium declinatum* (Kartsen); *Ceratium horridum* (Cleve); *Ceratium horridum* var. *buceros* (Zacharias); *Ceratium massiliense* (Gourret); *Ceratium massiliense* var. *protuberance* (Karsten); *Ceratium massiliense* var. *armatum* (Karsten) (First report from Odisha); *Ceratium tripos* (O.F. muller); *Ceratium tripos* var. *tripos* (Muller); *Ceratium tripos* var. *breve* (Ostenfeld & Schmidt); *Ceratium axiale* (Kofoid); *Ceratium tripos* f. *tripodiodes* (Jorgensen); *Ceratium breve* var. *parallelum* (Schmidt); *Ceratium breve* (Ostenfeld & Schmidt); *Ceratium breve* var. *breve* (First report from Odisha); *Ceratium furca* var. *hircus* (Schroder) and *Ceratium extensum formastriatum* (Nielsen) Few identified species using the keys are shown in Fig. 4 and Fig. 5.

The species composition, growth, diversity, and abundance of *Ceratium* species mainly depend on the physico-chemical parameters, i.e., both abiotic and biotic factors of the environment. Our results are in agreement with the report of Zarei et al. (2019), who investigated the changes in the population dynamics of three dominant dinoflagellates under the influence of biotic and abiotic variables, in the Zayandeh Rud Reservoir (Central Iran) and found that the statistically significant correlations could be established between abiotic parameters and dinoflagellates observed in their study. Higher temperatures were recorded during the monsoon season due to high relative humidity. Work carried out by Dodge and Marshall (1994) in the North Atlantic and adjacent seas reported that surface water temperature was the most important factor for determining the distribution and number of *Ceratium* species in a particular area.

Ceratium species are highly sensitive to even small changes in the sea surface temperature (Tambaru, 2022). Warm water harbours more species than cold water, and *Ceratium* can be used for defining ocean currents, temperature range and global changes (Dodge and Marshall, 1994). During the monsoon season, a large amount of sediment load makes the water less transparent. Transparency remains low during monsoon in comparison to the pre-monsoon season, with a lower sediment load and stable water column. The maximum water transparency was observed during the post-monsoon period owing to the absence of fresh runoff that got added from the river. Low pH was observed during the pre-monsoon and monsoon season compared to post-monsoon season. According to Das et al. (2008), the average pH value was higher during the post-monsoon season when compared to the pre-monsoon due to the utilization of CO₂ during the process of photosynthesis. Dissolved oxygen in the aquatic ecosystems is important for survival and the

normal development of metabolic processes of aerobic organisms (Hull et al., 2008). Across the sampling locations, the lowest dissolved oxygen content was observed during the post-monsoon season. Dissolved oxygen was maximum during the monsoon period due to prolonged heavy rainfall and high wind strength and intensity. Minimum dissolved oxygen concentration was observed during pre-monsoon period due to the presence of a greater number of diatom species in the study area. In a recent study, Edoa et al. (2022), reported a positive correlation of temperature with *Ceratium fusus*, *Ceratium massiliense*, *Ceratium macroceros* whereas DO showed a negative correlation with *Ceratium bigelowii*, *Ceratium massiliense* and *Ceratium macroceros*. *Ceratium* species can adapt to a wide range of temperature changes and yet are stable. The pre-monsoon period was characterized by the highest salinity corresponding with high rate of evaporation and reduced freshwater inflow whereas low saline condition prevailed in the wetter post-monsoon season.

The highest salinity was observed during the pre-monsoon period due to maximum evaporation of surface water and increased solar radiation. The lowest salinity was seen during the monsoon period due to addition of rain water and account of increased flow of river water. Pati et al. (2018) reported the occurrence of new species of *Ceratium* from the coastal waters of Paradip with dissolved oxygen and salinity as the primary factors regulating their growth. Banoo et al. (2022) worked on the spatial-seasonal variation of phytoplankton and physico-chemical variables at Paradip harbor water. They observed the dominance of Coscinodiscophyceae, followed by Dinophyceae and Bacillariophyceae and opined that salinity supports the growth of *Ceratium*, *Dinophysis*, *Pyrophacus* and *Prorocentrum* species. Their observations are in line with our results where salinity favoured the growth of *Ceratium* species. Fornshell et al. (1984) observed that variation in the abundance of the reported *Ceratium* species might have been influenced by the concentration of available nutrients in the surrounding water. Silicate concentration was maximum during the monsoon period due to frequent mixing of fresh water at the sampling site that corresponds to the increased abundance of silicate dependant diatom species and decrease in the *Ceratium* sp., as it is a good competitor of diatom species.

Dippner (1998) observed through simulation model that with increasing phosphate concentration there was an increase in flagellate biomass due to silicate limitation. A combination of phosphate increases due to river nutrient addition and silicate decrease, lead to a change in the functional groups with increasing flagellate group and decreasing diatoms. The results suggest that there might be an indirect impact of silicate reduction in coastal waters contributing to increase in flagellate abundance. Nitrite and nitrate concentration were minimum during the post-monsoon period owing to release from the soil and its subsequent dilution in the rain water. Phosphate concentration was higher during the pre-monsoon period which might be due to phosphate release from the bottom sediment at the sampling site. Somsap et al. (2015) reported that the abundance and bloom formation of

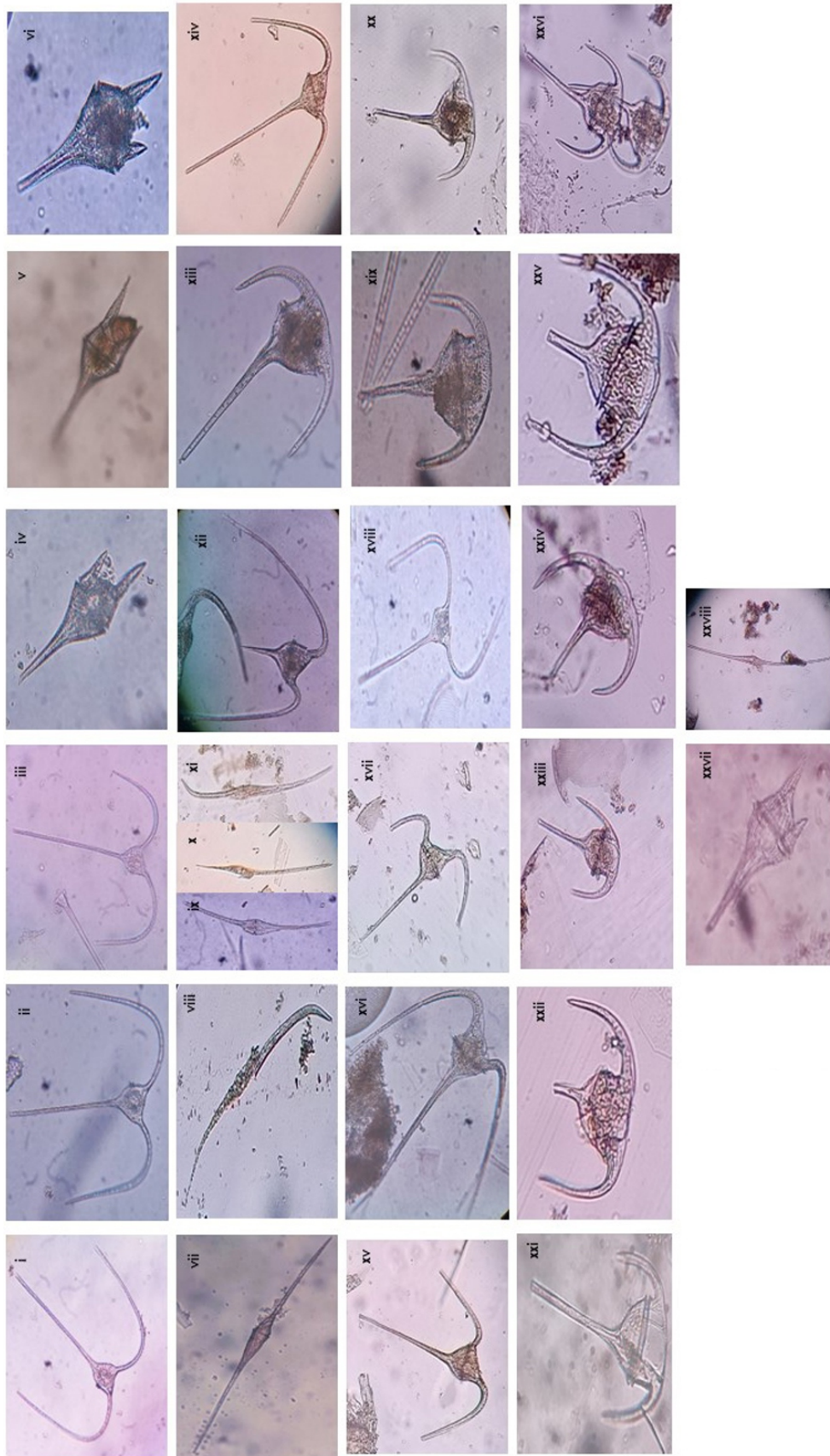


Fig. 4: I. *Ceratium contrarium* ii. *C. macroceros* iii. *C. trichoceros* iv. *C. furca* v. *C. furca* var. *furca-eugrammum* vi. *C. furca* var. *berghii* vii. *C. fusus* viii. *C. longirostrum* ix. *C. bigelowii* x. *C. extensum* xi. *C. infatatum* xii. *C. lunula* xiii. *C. declinatum* xiv. *C. horridum* xv. *C. horridum* var. *buceros* xvi. *C. massiliense* var. *protuberance* xviii. *C. massiliense* var. *armatum* xix. *C. tripus* xx. *C. tripus* var. *tripos* xxi. *C. tripus* var. *tripodoioides* xxiv. *C. tripus* f. *tripodoioides* xxiv. *C. breve* var. *parallelum* xxv. *C. breve* var. *breve* xxvii. *C. furca* var. *hircus* xxviii. *C. extensum* form *mastrictum*.

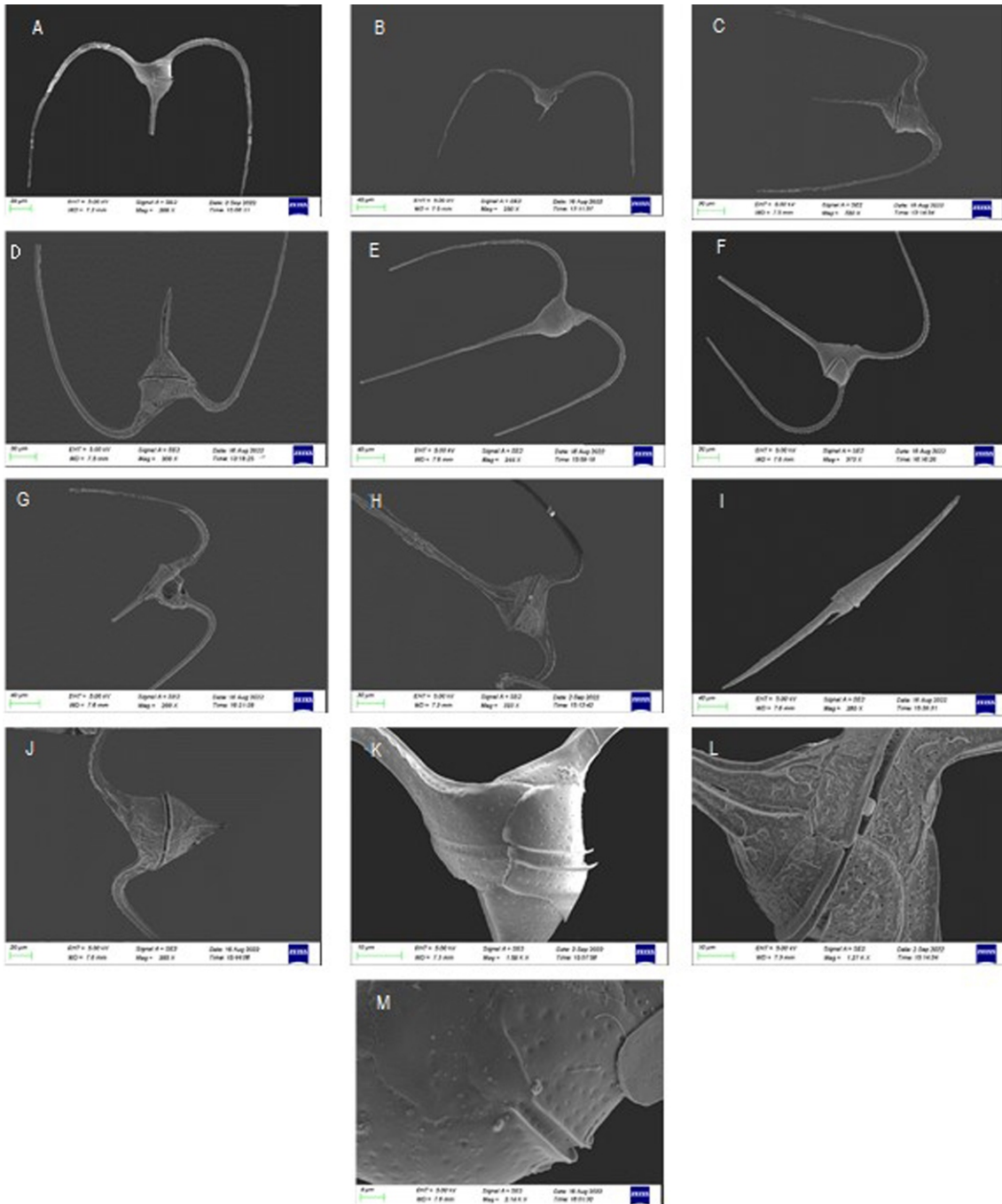


Fig. 5: Scanning Electron microscopic image of *Ceratium*-A. and B. Complete images of *Ceratium* species C.C. *lunula* (DV) D.C. *macroceros* (DV) E.C. *trichoceros* (DV) F.C. *contrarium* (DV) G.C. *lunula* (VV) H.C. *vultur f. vulture* (DV) I.C. *fusus* (DV) J. and K. Cell body showing complete separated epitheca and hypotheca (DV) L. Cell body showing plates. M. Cell body showing girdle. (Where, DV- Dorsal view; VV- Ventral view).

Ceratium furca species in the Inner Gulf of Thailand depends on the high dissolved inorganic phosphate concentration as also observed in our findings. Among the nutrient present in the coastal water, the phosphate concentration mostly influences the formation of horns in the *Ceratium* species. A work carried out by

Hasani *et al.* (2022) at Teluk Pandan Bay, Lampung, Indonesia reported that *Ceratium furca* population was mainly influenced by pH, phosphate and nitrate. Recently, Bryantseva (2023) reported 368 species of dinoflagellates in Ukraine by using 216 literary sources. Mahmudi *et al.* (2020) reported the occurrence of

Bray-Curtis Cluster Analysis (Single Link)

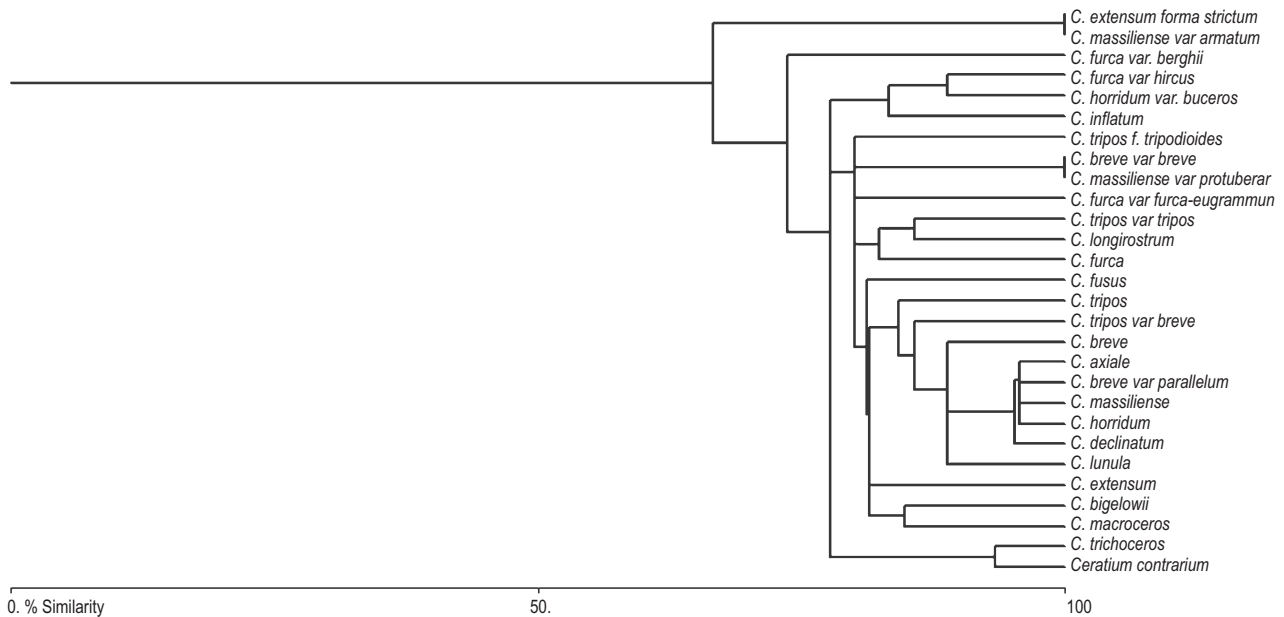


Fig. 6: Bray-Curtis cluster analysis showing similarity in *Ceratium* species in the surface waters of Dhamra.

Dinophyceae in Ambon Bay, Indonesia consisting of *Ceratium* species that were regulated by high temperature, nitrate and phosphate concentration, low dissolved oxygen with higher pH and salinity. The results obtained in this indicated a partial similar pattern with dominance of low temperature and high salinity in regulating the number of species. During the post-monsoon period, temperature was comparatively lower with high salinity favouring the occurrence of maximum number of *Ceratium* species in the coastal waters of Dhamra. Darwich and Alakash (2021) investigated the dominance of dinoflagellate species (*Ceratium furca* and *Ceratium macroceros*) during autumn and spring season (postmonsoon) and reported that the abundance of two species were high in the North Coastal waters of Lattakia city of Eastern Mediterranean. It was also observed that the horns of the *Ceratium* species were shorter and thicker during the post-monsoon period. Abundance of *Ceratium* species was highest in surface water where maximum light was available and our results are in agreement with the observations of Dodge and Marshall 1994 with regard to the role of surface water in deciding the distribution. Sahu *et al.* (2014) conducted a study in the coastal waters of Kalpakkam, South-east coast of India, Bay of Bengal to assess the seasonal variation in dinoflagellates community structure.

Genus *Ceratium* was found to be the most diverse one with 23 reported species. The results of this study, reported 28 species of *Ceratium* in the coastal waters of Dhamra, the indicating availability of favourable conditions for their growth. Lestari *et al.* (2021) carried out a study in the coastal waters of South Sulawesi, Indonesia and analysed phytoplankton diversity and abundance. Phytoplankton abundance was strongly

influenced by the Dinophyceae, especially *Ceratium furca*, a potential HAB species, and *C. furca* abundance was strongly and negatively correlated with species richness. Koffi *et al.* (2014) reported twenty-seven species in the Grand-Lahou lagoon and the reported species were similar to the composition of any tropical or subtropical region. New records (*Ceratium arietinum*, *Ceratium dens*, *Ceratium furca* var. *berghii* and *Ceratium pulchellum*) were reported from the Côte d'Ivoire part of the Gulf of Guinea from the ocean region. Vajravelu *et al.* (2018) investigated seasonal variation between physico-chemical parameters and phytoplankton diversity, community structure and abundance at Parangipettai coast, Bay of Bengal.

Amongst the phytoplankton species, *Ceratium breve*, *C. furca*, *C. fusus*, *C. massiliense*, *C. trichoceros* and *C. tripos* were observed, where in *C. tripos* and *C. furca* belonging to family Dinophyceae were the most common group observed during the sampling period. Dissanayake *et al.* (2021) in Sri Lankan waters had reported the occurrence of harmful dinoflagellates but they necessarily did not belong to the bloom forming group. Recently, Chen *et al.* (2023) reported formation of HABs by dinoflagellates in summer in the Qinhuangdao coastal sea of the Bohai Sea with temperature, salinity, and dissolved inorganic nitrogen as the primary factors influencing the formation of dominant HAB species. Yurimoto *et al.* (2015) had identified *Ceratium furca* as a major bloom forming dinoflagellate during early dry season in a mangrove estuary of Thailand. Saifullah *et al.* (2014) carried out a study on the composition and diversity of phytoplankton in the mangrove dominated river estuary in Sarawak, Malaysia and found dinoflagellates to be dominated by the genus *Ceratium*.

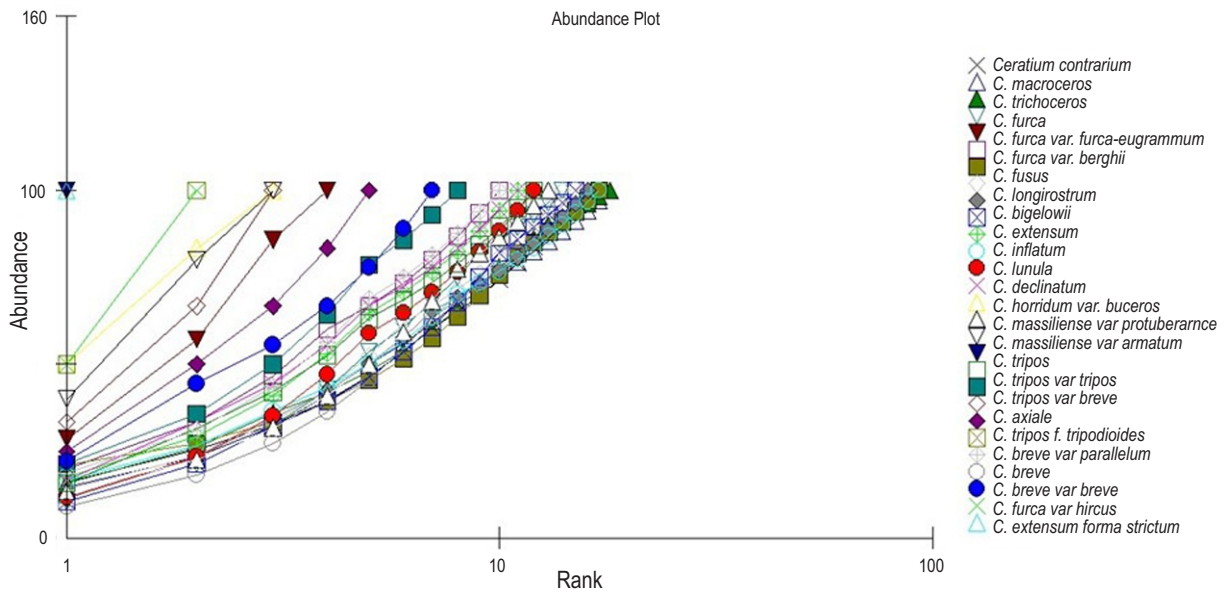


Fig. 7: K dominance curve showing the rank and abundance among *Ceratium* species.

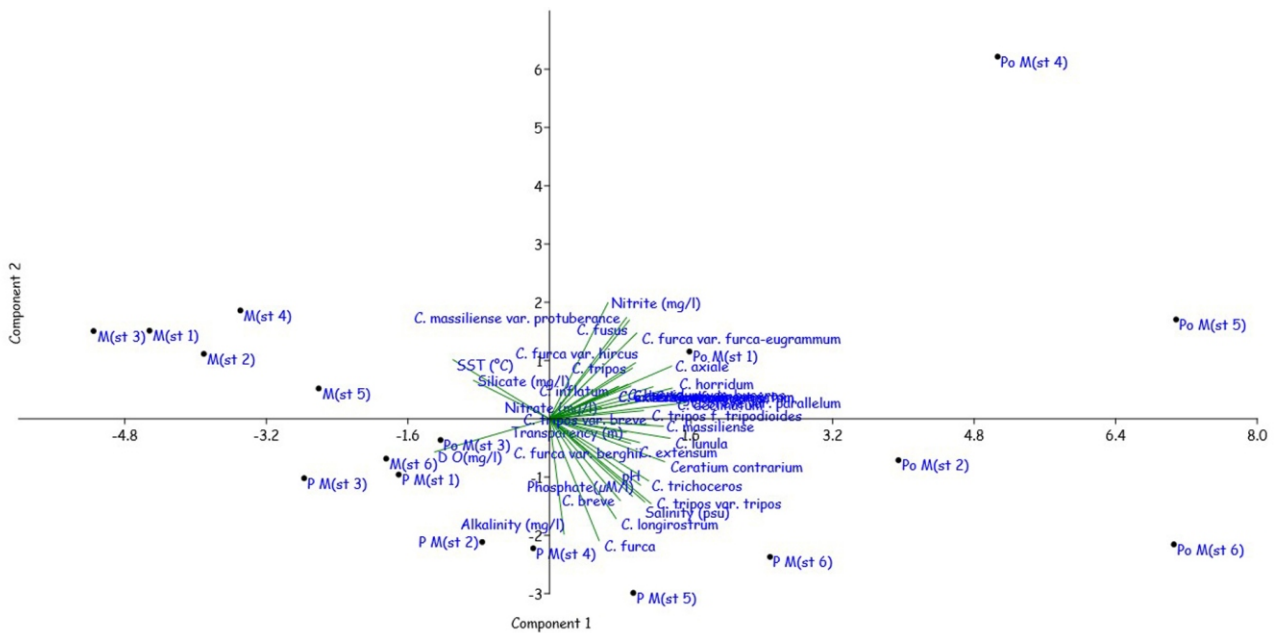


Fig. 8: PCA plot showing the correlation of physico-chemical parameters among different seasons and *Ceratium* species (where, PM =Pre-monsoon. M= Monsoon and Po M= post-monsoon).

They noted that *Ceratium lineatum* was toxic and were found in large numbers causing red tide. In this study, although bloom formation was observed, however, the formation of red tide was not confirmed. Godrijan *et al.* (2013) investigated the phytoplankton community and species dynamics in the coastal waters of less investigated eastern part of Northern Adriatic Sea. Their observation showed that during spring season, *i.e.*, March-

to April *Ceratium furca* and *Ceratium fusus* dominated the coastal waters as they thrive in low salinity. Edoa *et al.* (2022) also reported three harmful *Ceratium* species viz. *Ceratium furca*, *C. fusus* and *C. tripos* among 17 species of *Ceratium* in Kribi coast. In this study, *Ceratium fusus*, *C. furca* and *C. tripos* have been observed commonly. In another study by Shih *et al.* (2022) around Matsu Archipelago, *Ceratium fusus* was found to be the dominant

bioluminescent species during late summer. Some species reported in the present study also belong to the harmful group, however, no evidence of bloom formation was spotted during the study period. Bray-Curtis similarity matrix of the observed species reflects close association of *C. declinatum* (Fig. 6) exhibited more than 90 % similarity with *C. horridum*, *C. breve* var. *parallelum* and *C. axiale*. Similarly, *C. massiliense* showed close association with *C. breve* var. *parallelum*. Principal Component Analysis (PCA) biplot shows clusters of samples (*Ceratium* sp. and physico-chemical parameters) based on their similarity. Biplot uses points to describe the observations on the principal components and it also uses vectors to represent the coefficients of variables on the principal component.

Abundance plot (Fig. 7) shows the distribution pattern of available *Ceratium* species in the coastal waters of Dhamra. This plot explains the rank of the species in which *C. massiliense* var. *armatum* and *C. extensum formastrictum* are in rank 1 due to low abundance whereas *C. trichoceros* is at higher rank due to high abundance. This plot allows the comparison of dominance and diversity structure of *Ceratium* sp. and generally, species having low distribution are placed at higher rank and vice-versa. Distribution of *C. trichoceros* was highest followed by *C. contrarium* and both were placed almost close to each other in the abundance plot. In this study, the PCA plot, the points represent seasons with sampling station, and the vector represents *Ceratium* diversity with abiotic regulating factors. Sampling station and seasons depicted by points have similar scores on the components. Vector points in the direction which is most similar to the variable represented by the vector. Thus, vectors that point in the same direction correspond to variables that have similar response. It is clearly evident from the PCA plot that species located closer to each other have similar principal component scores. Salinity and nitrite seem to regulate the distribution of *Ceratium* species in the coastal water and primarily *Ceratium horridum*, *Ceratium axiale*, *Ceratium lunula*, *Ceratium trichoceros* as reflected in the PCA plot (Fig. 8).

The results show diversity of *Ceratium* species regulated by various nutrients in Dharma coastal waters and the coastal waters appear to be conducive for the growth of dinoflagellates especially species belonging to the genus *Ceratium*. The rich diversity and distribution of Dinophyceae could be due to availability of nutrients. Many species of *Ceratium* contribute to red tide condition, which in turn can cause ecological changes by altering the distribution of other species in coastal ecosystems. Hence, perpetual monitoring of toxic as well as non-toxic *Ceratium* species will help in better understanding of the changes visible in the coastal ecosystems.

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