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Winter monsoon phytoplankton community in the coastal waters of Northeastern Arabian Sea, with emphasis on harmful and non-indigenous species

L C Thomas, S Bijoy Nandan & K B Padmakumar*

Department of Marine Biology, Microbiology & Biochemistry, School of Marine Sciences, Cochin University of Science and Technology, Kochi, Kerala – 682 016, India

*[E-mail: kbpadmakumar@gmail.com]

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Phytoplankton community structure along the coastal waters of the Northeastern Arabian Sea (NEAS) was analysed for three years (2009, 2011 and 2012) during the winter monsoon season. The coastal waters of NEAS, especially Saurashtra coast are a region of high fishery potential. A total of 137 species of phytoplankton were identified. The community structure of phytoplankton showed significant inter-annual variability. The study highlights the persistence of certain non-indigenous phytoplankton species such as *Scrippsiella trochoidea*, *Karenia mikimotoi* and potentially harmful dinoflagellates mainly *Gonyaulax polygramma*, *Dinophysis acuminata*, *D. miles* and *Tripos furca* in the region that can raise probable threats towards the indigenous species and can cause harmful or toxic events. The increased abundance of diatom, *Pseudo-nitzschia* spp. that can produce toxins at certain threshold levels was also observed. The possible reason for the increased abundance of such groups can be suggestively due to the increased anthropogenic inputs into the coastal waters and intense fishing and maritime activity in the area.

[**Keywords**: Harmful microalgae, Non-indigenous species, Northeastern Arabian sea, Phytoplankton, Winter monsoon]

Introduction

Coastal marine ecosystems are dynamic, productive regions of World ocean that support a diverse group and wide variety of organisms. These systems are markedly influenced by various factors *viz*. oceanographic processes such as currents, waves, climate changes, human impacts, including overexploitation of fishery resources, habitat destruction, pollution etc. The physico-chemical characteristics of the coastal systems alter with these factors and are reflected in the assemblage of primary producers. Hence, the primary producers, mainly phytoplankton accounts to be a first line index towards alteration in the trophic structure and the sustainability of the ecosystem by external forcing[1,2].

Along the coastal waters of peninsular India, biannually reversing monsoon patterns modulates coastal currents, surface temperatures, nutrient availability, etc. Community composition and distributional pattern of phytoplankton get altered by these variations. Their assemblages depend on the ecological conditions like trophic (nutrients, food), physical (light, mixing and temperature) or biological factors (competition and predation)[3]. The changes in the community structure of phytoplankton influence the secondary and tertiary producers in an ecosystem.

The coastal waters of the Northeastern Arabian Sea (NEAS) ecosystem margined by Saurashtra region of north-west Indian coast (Gujarat coast) are a region of high fishery potential and fish landing[4]. Moreover, the region is one among the potential fishing zone (PFZ) advisories in India. The coastal belt also harbours highly diverse mangrove forests and coral reefs[5]. However, planktonic studies in this region are still fragmentary[5]. Northeast monsoon (Winter monsoon) is considered as the productive period of the Northeastern Arabian Sea. The process of convective mixing associated with winter cooling is the major physical forcing that controls the productivity pattern in the northern Arabian sea[6-8]. This mixing process results in the nutrient enrichment of the upper water column and favours growth and multiplication of primary producers, phytoplankton and subsequently supports secondary and tertiary production. The convective mixing induced biological production accounts much towards the carbon dynamics as well as the export flux in the region. The seasonal overturning of the water column and nutrient entrainment during the winter monsoon positively influence the phytoplankton community of the Northern Arabian Sea that remains oligotrophic during other seasons[9].

Primary producers play a pivotal role in an ecosystem and can be considered as the indicators of its sustainability. The phytoplankton community composition and its dynamics in the ecologically and economically significant northeastern Arabian sea coastal waters remain unclear till now. This paper discusses the community structure of phytoplankton along the coastal waters of NEAS during the productive winter monsoon (NE monsoon) season. Moreover, the study highlights the occurrence and persistence of certain harmful and non-indigenous algal species in these coastal waters.

Materials and Methods

The coastal waters of the Northeastern Arabian sea bordered by north-west Indian subcontinent were studied for the community composition of phytoplankton. The region observes increased nutrient input as well as biological production during the winter monsoon or northeast monsoon (November to early March). The phytoplankton community structure of these coastal waters with the prevailing hydrobiological conditions was studied for three years (2009, 2011 and 2012) during the winter monsoon season. Two sampling sites were surveyed during the study which includes off Veraval (21° N) and off Okha (22° N). Figure 1 shows the study area with sampling locations. Samples and data were not available for the year 2010 because of the unavailability of the research vessel. Three phases sampling *viz*., Phase 1 (P1- early February), Phase 2 (P2- late February) and Phase 3 (P3- early March) was carried out during 2009 and 2011 so that along with inter-annual variability, short-term changes within the season can also be analyzed. However, during 2012 sampling was carried out in two phases during March such as early March and mid-March.

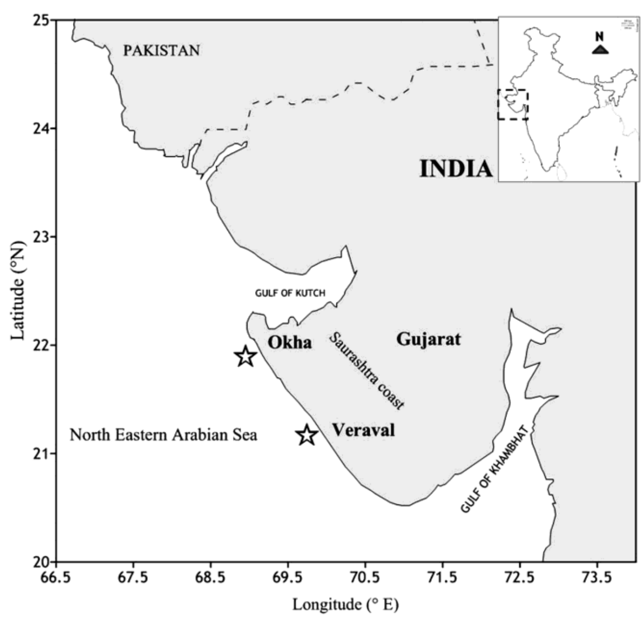

Fig. 1 — Study area- Northeastern Arabian Sea. Symbol (☆) denotes station locations

The study was conducted onboard FORV *Sagar Sampada* as a part of the Marine Living Resources Programme (MLRP) of Ministry of Earth Sciences. Sampling was carried out along the coastal waters off 22° N (Okha) and 21° N (Veraval) latitudes. Meteorological parameters mainly air temperature (AT), wind speed and directions were obtained through Automated Weather Station (AWS) onboard FORV *Sagar Sampada*. Vertical profiling of parameters such as temperature, salinity and density were recorded using Conductivity- Temperature-Depth profiler (CTD- *Seabird 911 plus*) attached with calibrated sensors for understanding oceanic processes. Water samples were collected using Niskin bottles (12 L) attached to the rosette sampler of CTD. The water samples were taken for chemical and biological analysis of various parameters. Major nutrients were analysed using a segmented flow Auto Analyzer (*SKALAR*) on-board by following UNESCO-JGOFS protocol (1994). Chlorophyll-*a* measurements were made spectrophotometrically[10]. Surface phytoplankton samples were collected by filtering ~30 litres of surface water through 20 µ bolting silk, and the filtrates were immediately analysed onboard for live materials and then fixed with 1-3 % Formaldehyde- Lugol's iodine solution for further laboratory analysis. Quantitative estimation and species identification of phytoplankton were done by employing Sedgewick- Rafter counting cell (1 ml in triplicate) under a compound microscope (Nikon Eclipse E200) following standard identification keys[11-15]. PRIMER V.6 was used for univariate and multivariate statistical analysis of data.

Results

Hydrography and meteorological conditions

Winter monsoon characteristics were evident along the coastal waters off Veraval (21° N) and Okha (22° N) with cool, dry northerly winds. Wind speed in the region was on an average 5 m s^{-1} with low humidity (< 80 %). A gradual decrease in wind speed observed from Phase 1 (~6 m s^{-1}) to Phase 3

(3.5 m s^{-1}). Air temperature (AT) varied from 23 to 27 ºC increased with phases (Fig. 2a) with the maximum during 2009 (27 ºC) and minimum during 2011 (23 ºC). A similar pattern was observed in the sea surface temperature (SST) distribution also (Fig. 2b). Average SST along the coastal waters of the northern Arabian sea was ~24 ºC. Surface salinity (SSS) of the region was on an average of 35.87 with the maximum during 2009 (36.2) and minimum during 2011 (35.2) (Fig. 2c).

Nutrient characteristics and chlorophyll-*a* pattern

The surface distribution of dissolved inorganic nitrate (DIN) showed significantly higher values (average 1 µM) along the coastal waters that reached 3.69 µM during 2011. Dissolved inorganic phosphate (DIP) of the region was on an average 0.5 µM, and maximum (1 µM) observed during 2011. Dissolved silicate (DSi) showed a varied pattern than that of DIN and DIP. Higher surface DSi observed along the coastal waters during 2009 (from 2 to 3 µM). A significant concentration of silicate recorded during 2012 late winter period (2.6 µM). Comparing the three years, 2011 observed lower DSi (1 µM). The surface distribution of chlorophyll *a* varied from 0.5 to 4 mg m^{-3} (Fig. 2d). Maximum chlorophyll concentrations observed during the winter monsoon period of 2011 (4 mg m^{-3}). Comparing the two sampling locations viz. off Veraval and off Okha, higher chlorophyll-*a* was observed along the coastal region off Veraval (21º N).

Phytoplankton abundance and community diversity

The phytoplankton abundance along the coastal waters of NEAS was on an av. 1.3 x 10^4 cells l^{-1} during the study period. Maximum abundance was observed during 2011 and phase-wise analysis observed peak abundance during Phase 3 (2.9 x 10^4 cells l^{-1}). The average diversity of phytoplankton (H’) for both Veraval and Okha varied from 1.29 to 3.6 (Fig. 3a). However, there observed a decreasing trend of diversity (H’) with years (Fig. 3c). The maximum diversity recorded (3.5) was during 2009 which decreased to ~1 during 2012. Concomitantly dominance (λ’) was higher during 2012 (0.6) when compared to the other two years (Figs. 3b, d).

Phytoplankton community structure

A total of 137 species of phytoplankton from 65 genera were identified from the coastal waters of NEAS. Considering the numerical abundance,

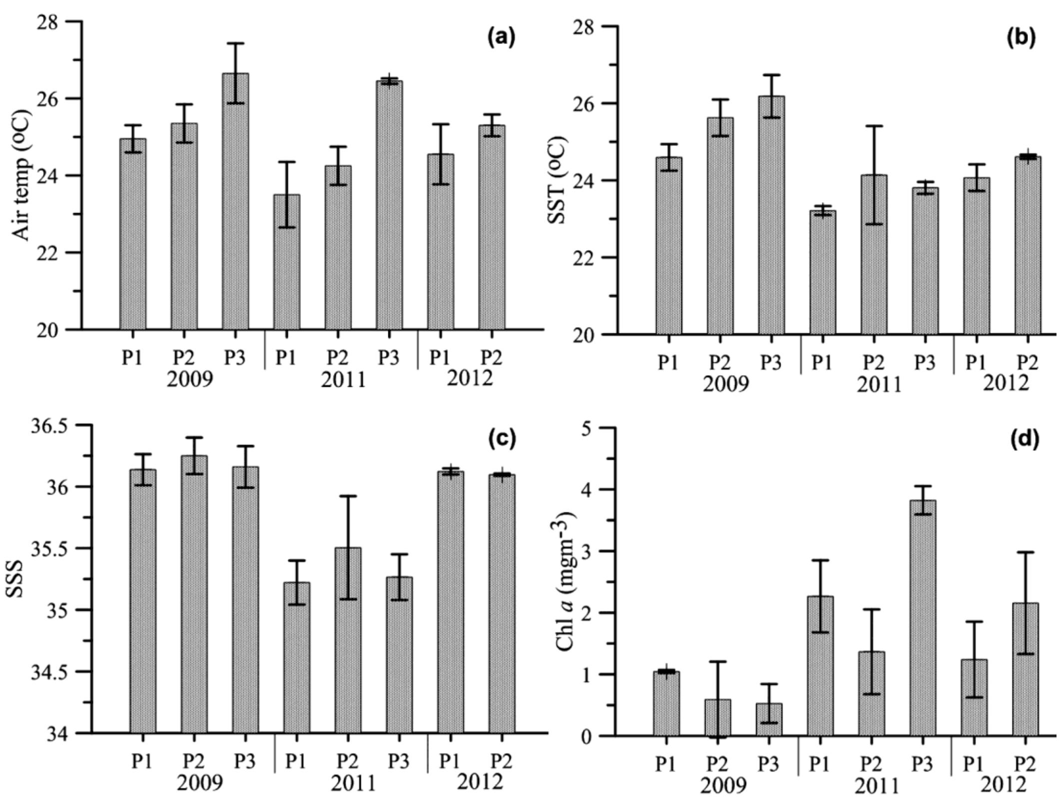

Fig. 2 — Distribution of physico-chemical parameters along the study area (a) Air temperature, (b) SST, (c) SSS, and (d) Chlorophyll-*a*

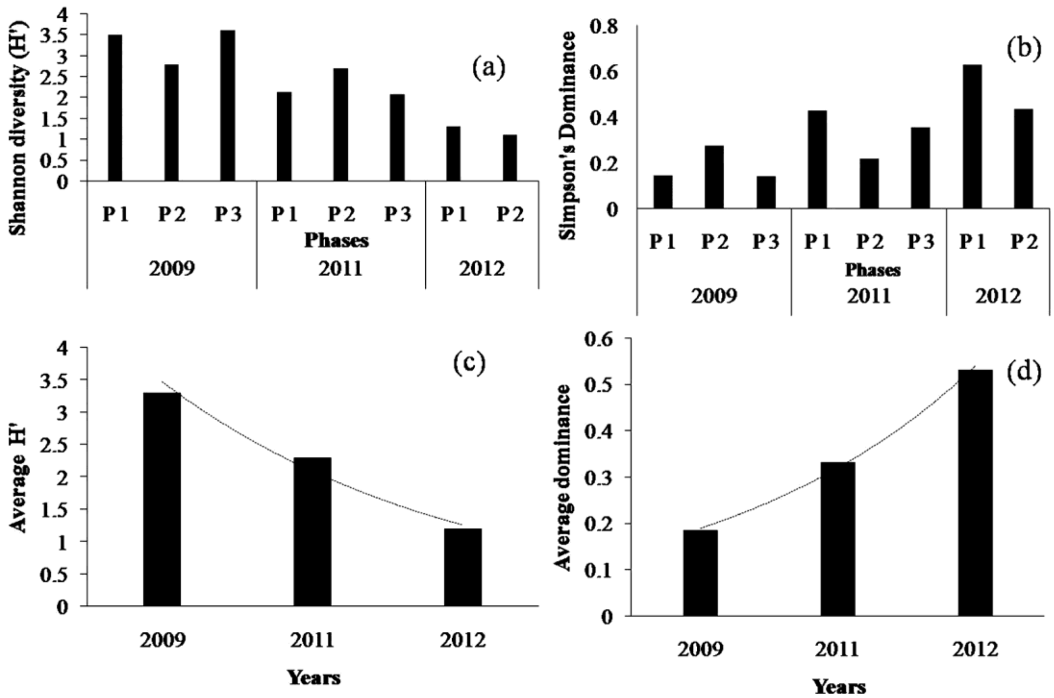

Fig. 3 — Variability in the indices of the diversity of phytoplankton community (a) H' Shannon diversity index, (b) Simpson's dominance index, (c) Average H', and (d) Average dominance

diatoms (Class- Bacillariophyceae) dominated (70-90 %) the phytoplankton community (Fig. 4a) followed by dinoflagellates (Class- Dinophyceae) (10-30 %). Few representations were there from class Cyanophyceae and Dictyochophyceae (0.5 to 1 %). Diatoms belonging to 90 species were identified during the study. Among the diatoms, centrales (subclass Coscinodiscophycidae) predominated (~56 % of diatoms) (Fig. 4b). The primary centric forms observed were several species of genus *Chaetoceros* such as *C. lorenzianus*, *C. socialis*, *C. laciniosus*, *C. decipiens*, *C. curvisetus*, *C. peruvianus* etc. The genus *Rhizosolenia* was represented by *Proboscia alata*, *Rhizosolenia hebetata*, *R. imbricata*, *R. hyaline* and *R. setigera.* Others were *Guinardia striata*, *G. flaccida*, *Thalassiosira* spp., (mucilaginous aggregations), *Leptocylindrus danicus*, *Eucampia* spp., *E. zodiacus* etc. The diatom subclass Bacillariophycidae (raphid pennates) were also observed in significant cell density (~25 % of diatoms) and was mainly contributed by various species of *Pseudo-nitzschia* such as *P. seriata*, *P. pungens*, *P. multiseries.* Mainly *Thalassionema nitzschioides* and *Thalassiothrix longissima* represented the diatom subclass Fragilariophycidae (~19 % of diatoms, araphid pennates).

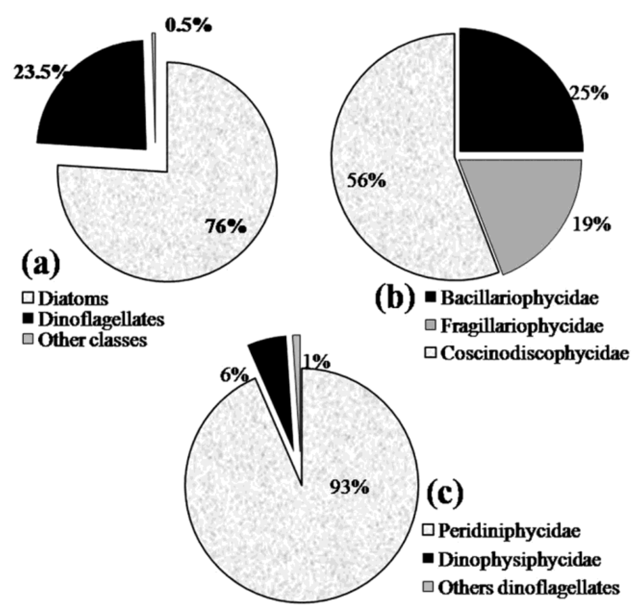

Fig. 4 — (a) Average percentage contribution of various classes of phytoplankton, (b) Subclass of diatoms, and (c) Subclass of dinoflagellates

Dinoflagellate community consisted mainly of thecate forms, including subclass Peridiniphycidae (~ 93 %) and Dinophysiphysidae (6 %) (Fig. 4c) and forty-two species of dinoflagellates were identified. The major dinoflagellates observed were

Tripos furca, *T. fusus*, *T. pentagonum*, *T. lineatum*, *Protoperidinium oceanicum*, *P. pellucidum*, *P. depressum*, *Gonyaulax polygramma*, *Scrippsiella trochoidea*, *Alexandrium* sp. belonging to Peridiniphycids and Dinophycids were represented mainly by *Dinophysis acuminata*, *Dinophysis miles*, *Ornithocercus magnificus*, *O. steinii*, *Amphisolenia bidentata* etc. Others present were *Gymnodinium* sp., *Karenia mikimotoi* (Subclass Gymnodinophycidae), *Noctiluca scintillans* (Subclass Noctilucophycidae), *Prorocentrum lima*, *P. micans*, *P. gracile* (Subclass Prorocentrophycidae).

Temporal variations in phytoplankton community structure

The structure of the phytoplankton community observed significant yearly variations between the winter monsoon season of 2009, 2011 and 2012. ANOSIM test carried out between the community of phytoplankton for the years observed significant variations (R-value ~0.8, at Sig: 0.001). SIMPER analysis observed average dissimilarity between the years as 96.43 %. Cluster analysis of the community using the Bray- Curtis similarity also observed three separate clusters for the three years (Fig. 5). The dominance index of phytoplankton community structure observed higher dominance during 2012 and was depicted in the k- Dominance plot analysis (Fig. 6). The variations in the analysis of phytoplankton community were analysed using non-metric multidimensional scaling using Bray Curtis similarity matrix and were overlaid with bubble plots (Figs. 7-9) for examining the variations in the distribution pattern of significant species. Detailed analysis of the community observed the increased abundance of centric diatoms mainly *Chaetoceros lorenzianus* and *Rhizosolenia hebetata* during the year 2009. Raphidpennate diatoms, contributed by various species of *Pseudo-nitzschia* were observed to be abundant during the 2011 and 2012 period along the coastal waters. Considering the araphid pennate community the abundance of diatoms *Thalassionema nitzschioides*, *Thalassiosira* sp. were observed during 2011. Dinoflagellate community also contributed significantly towards the inter-annual variations. The abundance of dinoflagellate was observed to increase during 2011 and further during 2012. Various dinoflagellate species such as *Tripos furca*, *T. lineatum*, *Protoperidinium* spp., *Gonyaulax*

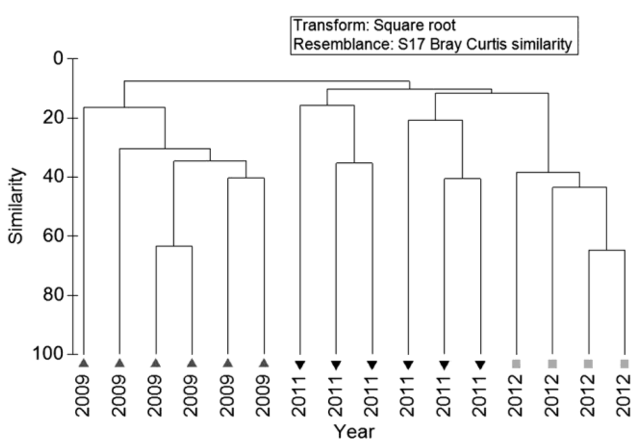

Fig. 5 — Dendrogram using phytoplankton abundance during 2009, 2011 and 2012

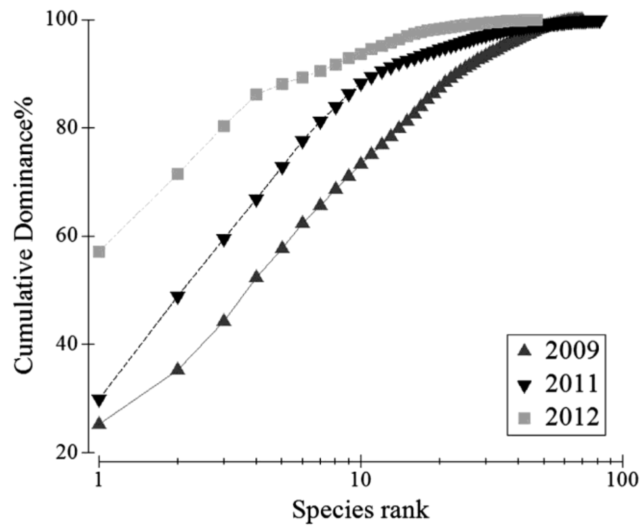

Fig. 6 — *k*-dominance plot for the phytoplankton community for three years

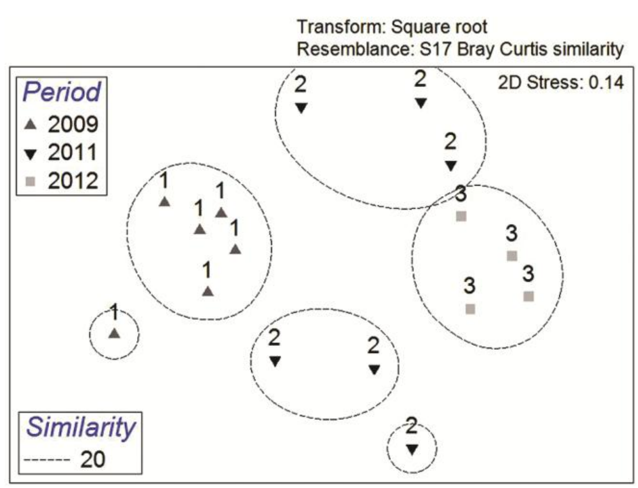

Fig. 7 — Non-Metric Multi-Dimensional Scaling (NMDS) plot for the similarity in the distribution of phytoplankton in the study region. The numerical representation in the plot indicates three years of study

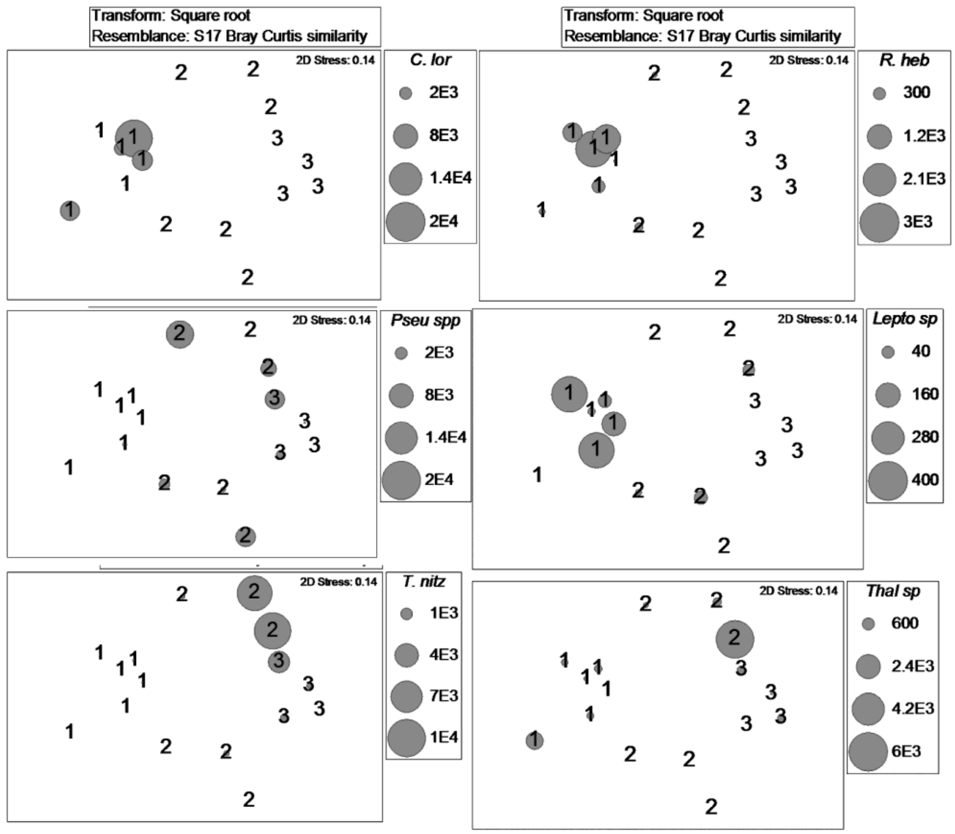

Fig. 8 — NMDS with bubble plot overlaid to observe variation in the distribution of major species of diatoms identified in the region (Species abbreviations and expansions: *C. lorenzianus* = *Chaetoceros lorenzianus*; *R. heb* = *Rhizosolenia hebetata*; *Pseu* spp. = *Pseudonitzschia* spp.; *Lepto* sp. = *Leptocylindrus* sp.; *T. nitz* = *Thalassionema nitzschioides; Thal* sp. = *Thalassiosira* sp.)

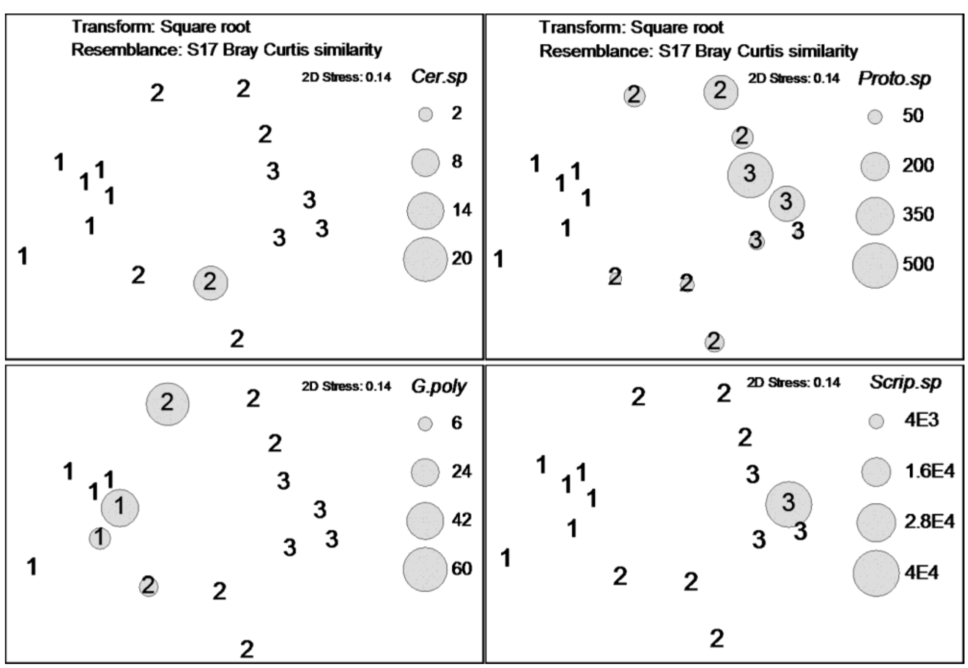

Fig. 9 — NMDS with bubble plot overlaid to observe variation in the distribution of significant species of dinoflagellates identified in the region. (Species abbreviations and expansions: *Cer.* sp. = *Ceratium* sp.; *Proto*. sp. = *Protoperidinium* sp.; *G. poly* = *Gonyaulax polygramma; Scrip. sp* = *Scrippsiella* sp.)

polygramma were observed to increase with the years. The spore-forming dinoflagellate *Scrippsiella trochoidea* was observed in significantly higher cell density during 2012 and was absent during the previous years.

Potentially harmful/ toxic and non-indigenous phytoplankton species identified from the surface waters

The study observed the presence and persistence of certain toxic as well as harmful algal species from the coastal waters of NEAS. The details of these identified organisms and their toxicity characteristics are given in Table 1. For convenience, these species were graded as potentially toxic (PTx) that have the potential to produce toxins under conducive environmental conditions and high biomass producers (HB) that result in deleterious effects due to increased reproductions and resulting in high organic biomass. This increased biomass can cause harmful effects due to oxygen depletion and gill clogging of fishes and shellfishes. One among the significant PTx grade species observed was diatom *Pseudo-nitzschia* spp., mainly *Pseudo-nitzschia pungens* and *P. multiseries.* These species have the potential to produce the domoic acid toxin under preferable environmental conditions. The trend analysis of *Pseudo-nitzschia* spp. observed yearly increase in abundance along the coastal waters of NEAS. The abundance of dinoflagellates also observed well-marked increase with years with the maximum during 2012. The major dinoflagellate identified, *Tripos* spp., was observed to be in increased abundance during 2011 and 2012 than that of 2009. Among the genus, *Tripos furca* was the dominant species to increase in abundance which can be graded as high biomass (HB) producing species. Other dominant harmful or toxic species observed included *Gymnodinium* spp. (PTx) up to 100 cells l^{-1}, *Alexandrium* sp. (suspected to be *A. tamarense*, PTx) up to 200 cells l^{-1}, *Dinophysis* spp. (PTx) up to 150 cellsl^{-1} contributed mainly by *D. acuminata*, *D. miles*, and *Gonyaulax polygramma* (HB) up to 200 cells l^{-1}.

The study identified certain non-indigenous species (NIS) from the area. *Scrippsiella trochoidea* was the major NIS observed in high cell density (~3.9 x 10^4 cells l^{-1}) along the nearshore waters which is generally considered as a temperate water bloom-forming species. Another NIS identified from the region was dinoflagellate *Karenia mikimotoi* (up to 50 cells l^{-1}) which is considered as temperate water bloom-forming species.

Discussion

The phytoplankton community along the coastal waters of the Northeastern Arabian Sea (NEAS) received very less attention till date. Being a productive region of Arabian sea during winter monsoon, open ocean waters are explored concerning the biological production, production rates and its variations[6,16]. However, a detailed analysis of the major primary producers, the phytoplankton, and their community structure are little. The present study unveils the community structure of phytoplankton

Table 1 — Potentially Harmful/ Toxic phytoplankton species identified from the coastal waters of NEAS

Species	Toxin	Toxicity	Cell density
Pseudo-nitzschia spp. (PTx) *P. pungens, P. multiseries*	Domoic acid (DA)	Amnesic Shell fish Poisoning (ASP) Gastrointestinal and neurological disorders	As blooms
Gymnodinium spp. (PTx)	Neurotoxins-Brevetoxin	Neurotoxic shell fish poisoning (NSP)- Fish and invertebrate kill, Asthma like symptoms in humans-aerosolization of Toxins- sea spray	upto 100 cells/L
Alexandrium sp. (Suspected to be *A. tamarense*, PTx)	Neurotoxin- Saxitoxins	Paralytic Shellfish Poisoning (PSP), Contamination of shellfish, affects fishes, birds and mammals	upto 200 cells/L
Dinophysis spp. (PTx) *D. acuminata, D. miles*	Okadoic acid	Diarrhetic Shellfish Poisoning (DSP)- Shell fish toxicity at low cell concentration (~200 cells/L)	upto 150 cells/L
Gonyaulax polygramma (HB)	Non toxic species	Red tide associated with massive kill fish kill- Anoxia, High sulphide and ammonia level resulting from cell decomposition	upto 200 cells/L
Tripos spp. (HB), *Tripos furca, T. fusus, T. lineatum*	Non toxic	Bloom forming dinoflagellate, High biomass, linked to eutrophication world wide Oxygen depletion, Ammonia production, Increased cell density with time, Unpalatability	upto 300 cell/L

along the coastal waters of NEAS during the productive winter monsoon period. Phytoplankton communities in the coastal waters are considered to be highly dynamic owing to its influence by both land and open ocean processes[17,18]. Unlike other biological components, phytoplankton can be identified as the first line index of the environmental changes due to its short lifespan and high reproductive rate[19].

Signatures of winter cooling and resultant convective mixing were evident in the study area with low SST, thoroughly mixed water column and enrichment of surface waters with nutrients. However, the intensity of the convective process was more prominent during Phase 1 that decreased in the following periods with the slackening of the northeast monsoon. Analysis of the phytoplankton community observed the dominance of diatoms in the region. *Chaetoceros lorenzianus* and *Rhizosolenia hebetata* dominated the phytoplankton community of the region that can be suggestively due to their ability to withstand turbulent conditions caused by the convective mixing processes[20]. Various species of diatoms are exalted with their ability to withstand physical disturbed water column but enriched with nutrients[21]. Abundance of *Thalassiosira* spp. along with *Rhizosolenia* and *Chaetoceros* spp. especially during Phase 1 of the 2011 winter monsoon characterized by intense convective mixing depicts the affinity of phytoplankton community towards successful *r- strategist* groups[22] in the area.

The community structure of phytoplankton observed significant inter-annual variations concerning the abundance as well as composition as evident from the cluster analysis (Fig. 5) and dominance plots (Fig. 6). Community variations were much due to numerical variations within the existing species rather than drastic species changes. These changes can be corroborated with the physico-chemical environment prevailing in the region. The intensity of winter mixing was observed to be higher during 2011 and 2012 than that of 2009 and thereby the year 2009 experienced comparatively higher SST and lower nutrient input except for dissolved inorganic silica.

The pulse of nutrients towards the coastal waters of the region can be attributed primarily to the winter time overturning. However, the input of macro as well as micronutrients from the terrigenous supply into these coastal regimes cannot be nullified[23]. On an average, the dissolved inorganic forms of nitrate and phosphate observed were considerable (DIN ~1 µM, DIP ~ 0.5 µM) in the surface waters. Three-year analysis observed higher DIN values during 2011 and 2012. The increased numerical abundance of raphid pennate diatoms *Pseudo-nitzschia* spp. during these periods can be favourable due to the nitrate enrichment of these waters during which DIP slightly decreased. Various species of *Pseudo-nitzschia* are known to flourish when there is an increase in nitrate loading[24]. The phytoplankton biomass, as well as its community structure, very well correlates with the type of nitrogen species as well as its availability in the system[25]. *Thalassionema nitzschioides*, a pennate diatom was also observed to flourish when there was an increased DIN in the surface waters. The species is earlier reported to have a strong positive correlation with the nitrate values elsewhere in different coastal systems[26]. The diatom community structure observed the abundance of larger forms mainly long chains of *Rhizosolenia hebetata*, *Chaetoceros lorenzianus* during 2009. Higher concentrations of dissolved silica might have favoured their abundance in the turbulent coastal waters[27].

The contributions of dinoflagellates were lesser when compared with that of the diatoms. The community was represented mainly by thecate forms (mainly Peridiniphycids) such as *Tripos* spp., *Protoperidinium* spp., *Gonyaulax* spp. Dinoflagellates are generally considered to be less turbulent tolerant forms[22] however; certain thecate dinoflagellates are observed to thrive well in adverse environmental conditions[28]. The dinoflagellates such as *Tripos furca*, *Protoperidinium* spp. were reported from the Southeastern Arabian sea during intense upwelling condition substantiating their capacity to withstand in the disturbed water column[29]. When compared with that of thecate forms athecate dinoflagellates were lesser in the community.

The phytoplankton community studies along the coastal waters of NEAS observed presence as well as the abundance of certain harmful algal species. The diatom *Pseudo-nitzschia*, till date the only known diatom with toxin production (PTx) was observed in abundance along these waters. The diatom genus produces a potent neurotoxin Domoic acid (DA)[30]. Even though noticeable discolourations were not observed in the surface waters, higher abundance of certain *Pseudo-nitzschia* genus was identified in the microscopic observations. The presence of *Pseudo-nitzschia* cells alone will not confirm their toxicity nature. Various studies on the toxicity of *Pseudo-nitzschia* state that the production of toxin occurs in certain environmental conditions that fall in a narrow range of variance[31]. The favourable conditions leading to the production of Domoic acid are still unclear. Various studies on the toxicity mechanism of the genus observed that, conditions of nutrient limitations leading to physiological stress mainly by silicate, phosphate, micronutrients like iron[31-33] and elevated pH[34] may act as triggering factor for toxin production in the *Pseudo-nitzschia* sp. Along the coastal waters of NEAS, the abundance of *Pseudo-nitzschia* cells observed a gradual increase in abundance with years. Physiological studies on the genus have shown that blooms of the genus are often related to nutrient enrichment of coastal waters[35,36]. The increased abundance of *Pseudo-nitzschia* along the coastal waters of the eastern Arabian sea was described earlier from the region off Goa[37] and from the coastal waters of the Southeastern Arabian sea during summer monsoon season[38]. Even though toxic events relating to domoic acid production from *Pseudo-nitzschia* is not yet reported, the possible chances of toxin production cannot be ruled out.

Apart from diatoms, even though dinoflagellates were represented in a fewer proportion, their abundance was observed to be higher in the winter monsoon of 2011 and 2012. This increase was mainly contributed by various species of *Tripos* mainly *Tripos furca*. The species is a non-toxic bloom forming dinoflagellate, however its harmful effect is due to the high biomass (HB) resulting from the bloom formation. The genus has been correlated with the eutrophication worldwide[39]. Oxygen depletion and ammonia production resulting from high biomass impart harmful effects towards the coastal ecosystem. Moreover, the unpalatability of the genus is a cause of concern. There was occurrence of certain potentially toxic (PTx) dinoflagellates such as *Gymnodinium* spp. (PTx), *Alexandrium* sp. (Suspected to be *A. tamarense*, PTx), *Dinophysis acuminata*, *D. miles* (PTx), *Gonyaulax polygramma* (HB) in the coastal waters also raise a concern for the marine ecosystem health of the region.

The community analysis of phytoplankton observed the presence of certain non-indigenous species along the coastal waters of NEAS. The primary such species observed was thecate dinoflagellate *Scrippsiella trochoidea* (NIS, PTx) which was recorded in higher cell densities along the waters (~3.9x 10^4 cells l^{-1}). This is considered as a temperate water bloom-forming species but observed to extend its territorial boundary with time[40]. Recently *Scrippsiella* sp. has been reported in higher cell densities along the waters off Goa[41]. Similarly, athecate dinoflagellate *Karenia mikimotoi* (NIS) was identified from the study area in significant cell densities. Even though the toxicity mechanism is still unclear the species is known to release ichthyotoxic hemolytic compounds[42]. The species is also considered as temperate water bloom-forming species, however, recent studies observe their blooms and associated mortality of marine organisms in other regions of the World ocean[43]. Along the Indian waters, the reports on the occurrence as well as the bloom of the species are rare but were reported as bloom along Cochin barmouth along the Southeastern Arabian sea[44]. Their study describes *Karenia mikimotoi* as an invasive species. Prior to that, the species has been reported from the coastal waters near Mangalore port along south-west coast of India[45].

From the present study as well as previous observations, it becomes clear that the non-indigenous and invasive species reports were mostly from the regions in and around ports having various maritime activities. Cochin, Mangalore, Goa, and Gujarat areas are regions of intense shipping activities. Moreover, Gujarat coast harbours major ship breaking yards. All these activities pave the way for ballast water discharge in these regions which can cause alien invasion into these waters. Mostly spore-forming microalgae are transported through these pathways[46]. Even though the Global Ballast Water Management Program of International Maritime Organization has already set up several protocols for the management of ballast water strict compliance of these need to be reviewed.

The coastal waters of Gujarat (Saurashtra coast) are regions of high fishery potential and fish landings. Fishery statistics of 2014 has reported marine fish production of ~7 x 10^5 tonnes from Gujarat[4]. The observations of toxic or potentially harmful algae from these waters are a cause of concern. Even though no massive harmful algal bloom and associated fish kills have been reported from these regions possible chances in the near future cannot be neglected. The coastal waters off Saurashtra are influenced by anthropogenic activities, industrial, agricultural and domestic waste discharge[47]. These terrigenous inputs can alter the nutrient stoichiometry of the coastal waters and can favour the growth of nuisance algal groups.

Conclusion

The coastal waters off Saurashtra (NEAS) support a diverse phytoplankton community dominated by diatoms. The region is considered to maintain high fishery potential with significantly higher marine fish landings. Presently no HAB aftermaths reported from the coastal waters off Saurashtra. This study suggests Saurashtra coastal waters are vulnerable to future HAB events and related deleterious effects towards marine ecosystem through habitat alteration. Industrial and agricultural runoffs towards the coastal waters can cause deleterious effects towards the coastal ecosystem. Regular monitoring of toxic species along the coastal waters can predict possible HAB events. Regarding Non-indigenous/ Invasive species strict implementation of recommendations by the Global Ballast Water Management Program of International Maritime Organization is required. Moreover, a proper database on the NIS needs to be developed to check alien invasions in these waters.

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Conflict of Interest

The authors declare that they have no conflict of interest.

Author Contributions

LCT wrote the manuscript with input from KBP. LCT and KBP conducted the field study. LCT conducted taxonomic identifications. SBN supervised this study and provided research materials.

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