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Recurrent dinoflagellate blooms in the South-eastern Arabian Sea - A preliminary assessment with focus on *Ornithocercus magnificus* blooms along the nearshore waters off Dakshina Kannada, South-west coast of India

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ABSTRACT

Frequent bloom incidences of the dinoflagellate *Ornithocercus magnificus* Stein, 1883 along the surface waters off South-eastern Arabian Seas (SEAS) have been reported since 2015 and specifically during the years 2015, 2019 and 2020. All these blooming incidences coincided with the strong El Nino phases in the Indian Ocean. The present study addressed the bloom (1.65×10^6 cells l^{-1}) of this species in the nearshore waters (7 m depth) off Dakshina Kannada (Surathkal and Chitrapur) on 11.02.2016 which occurred during pre-monsoon period and corresponding to the super El Nino year 2015/2016. A detailed evaluation of the physico-chemical characteristics and phytoplankton abundance as well as community structure was made, concurrent to the three phases *viz*., pre-bloom, bloom and post-bloom periods in this region. The study revealed that the bloom occurred in high saline (35.0±0.91 PSU), well oxygenated (7.414±0.823 mg l^{-1}) and nitrogen limited waters (oligotrophic conditions) and had a positive correlation with oceanic nino index (ONI; $r_s = 0.790$, $p<0.001$). Some of the *O. magnificus* (3%) harboured ectosymbionts probably cyanobacteria in their cingulum in response to the beginning of a stratified oligotrophic condition in this region. The water quality was fair during the bloom period with no conspicuous discolouration of the surface waters. The present study also attempted to evaluate the influence of the increasing frequency of the *O. magnificus* blooms on the oilsardine fishery along the SEAS.

Keywords: Cyanobacteria, Dinoflagellate, Ectosymbionts, Nitrogen limited waters, Oilsardine, Pre-monsoon season, SEAS, Sea surface temperature (SST)

Introduction

Ornithocercus sp., belonging to the family Dinophysaceae and characterised by complex structure is an attractive planktonic dinoflagellate represented by 15 species globally (Cleve, 1900, 1901, 1903; Kofoid, 1907; Kofoid and Skogsberg, 1928; Wood, 1963, 1968; Gomez, 2005). In the Indian Ocean also their occurrence has been reported by Taylor (1976) and Wood (1963) identifying 9 and 8 species of this genus respectively. Kuzmenko (1975) has recorded the presence of three species belonging to this genus from the northern Arabian Sea. Furthermore, Syed *et al*. (2008) identified 5 species of this genus from the surface tropical waters of northern Arabian Sea shelf off Pakistan, of which four were new records.

Earlier Lewis (1965) reported a considerably high abundance of *Ornithocercus magnificus* Stein, 1883 (1.175×10^5 cells l^{-1}) in association with a red tomato soup bloom of *Gonyaulax polygramma*,off Arabian Sea at 10 m depth during the post-monsoon season. High densities of the species in the Arabian Sea, has also been addressed by Subrahmanyan (1958) indicating discolouration of surface waters, though the term "bloom" was not mentioned.

Other than these reports, blooms of this genus in the surface waters of Arabian Sea have been a rare occurrence. However, in the recent decades, blooms of this genus have been reported frequently from the northern Indian Ocean. Karthik *et al*. (2017) reported the bloom of *O. magnificus* in the coastal waters (surface) off Karnataka during the pre-monsoon of 2015. In addition, Lavanya *et al*. (2020), have also reported on the blooms of *O. magnificus* in the inshore surface waters, off Kochi, Kerala during the post-monsoon season of 2019. Interestingly, after the subsidence of the bloom in 2019 and within a gap of one month, the species was observed once again in high abundance off Kochi inshore waters during February 2020, with presence of ectosymbionts harboured in the crown of the cells.

O. magnificus is used as an indicator species for climate and environmental change along the South Korean waters (Kim *et al*., 2008). Korea being in the temperate region, the warmest water temperature recorded was 23.7^{0}C, however, the presence of 19 new tropical dinoflagellate species, including the indicator species *O. magnificus* in very high abundance, indicated a significant change in the dinoflagellate composition in Korean waters. These observed changes were attributed to warming up of the coastal waters (Kim *et al.,* 2008). Kim (2013) reported the presence of 34 as yet unrecorded dinoflagellate species from South Korean waters and 23 of these were tropical species. Though the presence of *O. magnificus* in the Indian tropical waters is common and generally not considered as harmful, its high abundance in the surface waters has been linked to increasing sea surface temperatures (SST) (Lavanya *et al.*, 2020) and consequent environmental changes. Unlike blooms of *Trichodesmium* sp., which are common during the pre-monsoon season, frequent blooms of *Ornithocercus* sp. along the surface waters of Arabian Sea along the SEAS is rare. In a span of 5 years (2015-019), the frequency of occurrence of *O. magnificus* blooms along the west coast of India has been increasing (Karthik *et al.,* 2017; Lavanya *et al.,* 2020) indicating a discernible change in the marine ecosystem especially in terms of increased SST which in turn could have negative impacts on primary productivity and the marine food web (John *et al.,* 2018). Furthermore, the presence of this species in the gut of oilsardine (caught by bottom gillnets and bottom trawlnets during the pre-monsoon), also leads to a point of concern on the possible cause of the blooming of this bottom dwelling species in the surface waters (Kagwade, 1964; Dulkhed *et al.,* 1972). Thus, mere occurrence of the bloom or even a higher abundance of this species needs to be extensively evaluated. Even though Karthik *et al.* (2017), did not report any correlation of the bloom of *O. magnificus* with SST, the bloom of this species occurred during pre-monsoon concurrent to the El Nino year (2014-15). The present bloom also occurred during the pre-monsoon of a very strong super El Nino year (2015-16).

The present study investigated the variability in the physico-chemical attributes of the nearshore surface waters, off Dakshina Kannada, south-west coast of India, during three phases of *O. magnificus* bloom that occurred on 11.02.2016 and probed in to the increasing frequencies of *O. magnificus* blooms along the SEAS.

Materials and methods

Study area

Two nearshore stations, Surathkal (13°0'23.882"N; 74°46'43.097"E; 6-7 m depth) and Chitrapur (12°56'32.761"N; 74°47'25.56"E; 7 m depth) off Mangaluru in Dakshina Kannada District were monitored (Fig. 1). Seawater and phytoplankton samples were collected on a monthly basis.

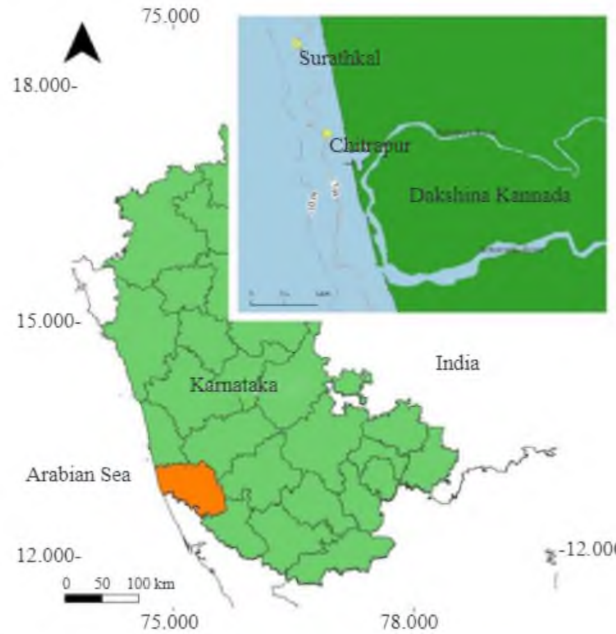


Fig. 1. Map showing the sampling locations in the nearshore waters off Dakshina Kannada on 11.02.2016

Sample collection and data analysis

Collection and analysis of water samples

Surface seawater samples were collected during the early morning in polypropylene bottles and brought to the laboratory for further analysis of their physico-chemical characteristics. Surface water temperature was measured using a centigrade mercury thermometer (-10˚C-110˚C; OMSONS). Salinity was measured potentiometrically using a multi-parameter instrument (WTW 320i, Xylem Analytics LLC, Germany). For dissolved oxygen estimation, water samples collected in 125 ml BOD bottles were immediately fixed with Winkler reagents and subsequently analysed following Winkler's method (Strickland and Parsons, 1968). Chlorophyll *a* was estimated by filtering the water samples using GF/F Whatman glass fibre filters of pore size 0.7 µm followed by pigment extraction using 90% acetone and estimation in spectrophotometer (UV-VIS Lambda 365, Perkin Elmer). Dissolved inorganic nutrients (ammonia, nitrite, nitrate, phosphate and silicate) were determined using standard analytical methods (APHA, 1981). Water quality indices (WQI) were also evaluated, as per the selected environmental indicators of USEPA (2012).

Phytoplankton sample collection and analysis

Phytoplankton samples were collected by horizontal hauling of a standard plankton net of mesh size 20 µm and 0.5 m^2 mouth diameter, at a speed of 2 knots for 10 min and preserved using 4% formaldehyde. Enumeration and identification of the phytoplankton samples were carried out following the standard phytoplankton identification manuals (Subrahmanyan, 1958; 1968) under light microscope (LEICA ICC50).

Statistical analysis

The Shannon and Weiner index was estimated to determine the phytoplankton species richness and diversity in the bloom (Shannon and Weaver, 1949) using the statistical software PRIMER (Ver.6.3.2). Spearman correlation analysis (2-tailed) was also carried out using SPSS software (SPSS Statistics 23) to evaluate the significant relation of various abiotic variables with the abundance of *O. magnificus*.

Secondary data

To understand the intensity of El Nino and La Nina events, oceanic nino index (ONI) data pertaining to 2015-2019 years were accessed from the National Oceanic and Atmospheric Administration (NOAA). Monthly average rainfall data during the study period was collected from Indian meteorological department. Monthly fish catch data for the period was taken from data bank of National Marine Fisheries Data Centre (NMFDC) of ICAR-Central Marine Fisheries Research Institute (ICAR-CMFRI).

Results and discussion

Bloom characteristics

Microscopic examination of the phytoplankton sample collected on 11.02.2016 from the nearshore waters off Surathkal (1.65×10^6 cells l^{-1}) and Chitrapur (7.6×10^5 cells l^{-1}) in Dakhsina Kannada revealed *O. magnificus as* the dominant phytoplankton species responsible for the bloom (Fig. 2). The incidence of this genus in the Arabian Sea with exclusive occurrence restricted to pre-monsoon phase has been reported by Subrahmanya (1958), Kuzmenko (1975), Gomez (2005), Syed *et al.* (2008) and Karthik *et al.* (2017), with an exception on their occurrence during post-monsoon by Lavanya (2020). The length of *O. magnificus* ranged from 70-100 µm with 6-8 complete ribs (Wood, 1954, 1968; Taylor, 1976). Coinciding with the earlier reports, the present bloom also occurred during the pre-monsoon period. In order to have a detailed seasonal evaluation of the bloom, the occurrence and abundance was monitored and categorised as Pre-bloom, Bloom and Post-bloom phases. The pre-bloom sampling was conducted on 25.01.2016 and were characterised by a cell count of 6.6×10^3 cells l^{-1}. A spike in their abundance was noticed in February reaching to a maximum abundance (1.65×10^6 cells l^{-1}) and hence was categorised as bloom period. Following the bloom period, a subsequent decline in their abundance reaching to zero was noticed during March 2016 and hence was categorised as the post-bloom phase. There was no conspicuous discolouration of the surface waters during the sampling periods, even during the bloom, though Subrahmayan (1958) had mentioned about the discolouration of waters associated with high densities of this species. Sighting of marine birds such as seagulls and terns during the bloom period indicated evidence of fish availability in the region.

Water quality and physico-chemical characteristics during the bloom

The physico-chemical characteristics differed during the three distinct phases of the bloom (Fig. 3). The bloom period was notable for significantly higher salinity (35.2±0.91 PSU) ($p<0.05$) and oxygenated waters ($p<0.05$) with dissolved oxygen concentration of 7.414±0.823 mg l^{-1}, higher than the pre-bloom and post-bloom phases. The SST during the bloom ranged from 30 to 30.5°C and was relatively higher than the pre-bloom and lower than the post-bloom phase. The average chlorophyll a concentration was observed to be 3.382±0.53 mg m^{-3} ranging between 2.72 to 3.8±0.53 mg m^{-3} with lowest observed during the pre-bloom phase. Inorganic phosphate was in the range 0.03-0.04±0.01 mg l^{-1}, while nitrate (0.003±0.01 mg l^{-1}) and nitrite (0.005±0.01 mg l^{-1}) concentrations were observed to be low during the bloom revealing that the waters were N_2- limited, indicating the beginning of an oligotrophic condition. Tarangkoon *et al.* (2010) recorded occurrence of symbiont-bearing dinoflagellates in oligotrophic water masses with low nutrient (N-limited) and chl *a* concentration. The average ammonia concentration was observed to be 0.065±0.045 mg l^{-1}, while the ammonia concentration showed a sharp decline from the pre-bloom phase to almost nil during the post-bloom phase. The maximum ammonia concentration (0.11±0.045 mg l^{-1}) observed during the pre-bloom phase was not above the permissible

Fig. 2. *O. magnificus* collected during the bloom observed on 11.02.2016 in the nearshore waters of Dakshina Kannada

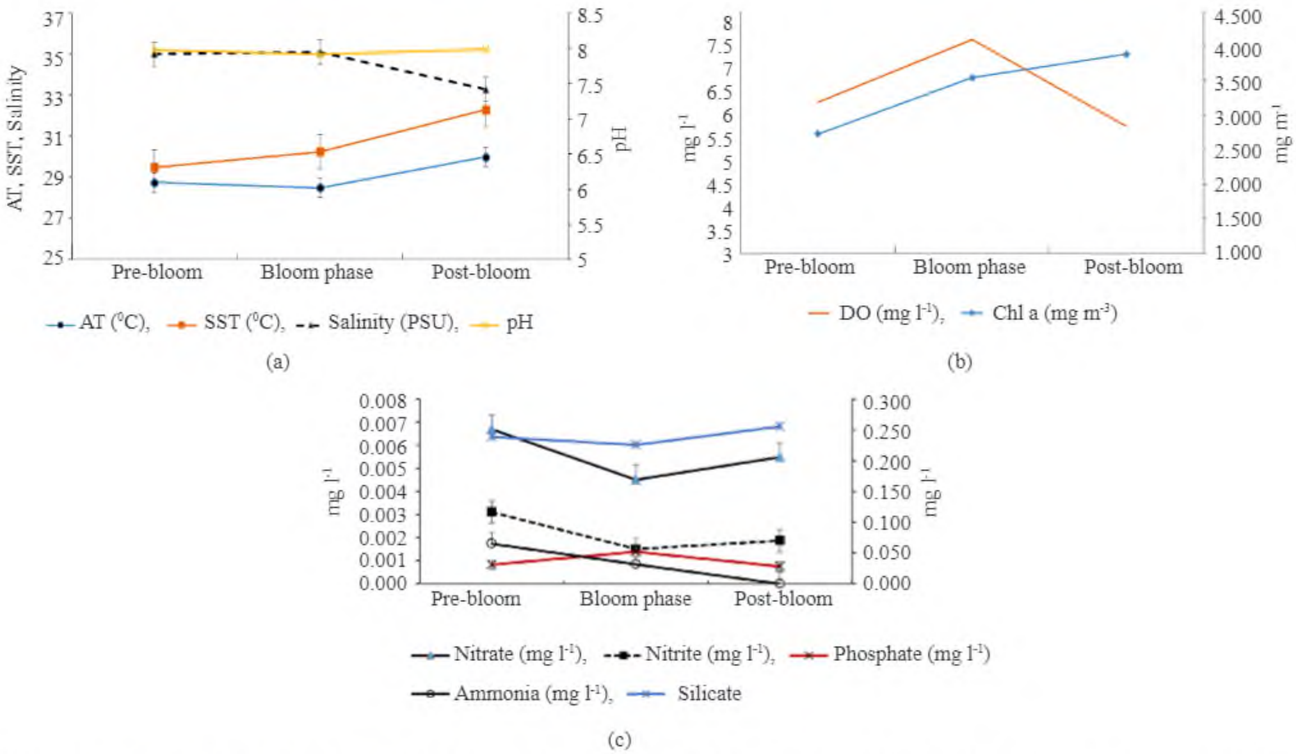


Fig. 3. Physico-chemical parameters during the diffierent phases of the bloom of *O magnificus* off Dakshina Kannada. (a) Air temperature (AT), (b) Seasurface temperature (SST) and (c) Salinity (PSU)

limit for coastal waters, hence fish mortality was also not observed. This also indicates that other phytoplankton species which could not survive or tolerate lower nutrient levels or an oligotrophic condition in the ambient waters started degrading. There was a marked decrease in the diatom abundance during the post-bloom phase. The water quality index as per USEPA (2021) rating was fair during the bloom. The variation in physico–chemical parameters was also studied for the years from 2014 to 2016 during the months from January to March (Fig. 4).

Phytoplankton community structure

O. magnificus dominated with a contribution of 54-99% of the total phytoplankton population at all stations, during the pre-bloom and bloom phases and declined gradually to a complete absence during the post-bloom. The abundance of *O. magnificus* during the pre-bloom, bloom and post-bloom phases is represented in Fig. 5.

Analysis of phytoplankton samples revealed the presence of 53 species, majority of them being diatoms (32 species), followed by dinoflagellates (21 species) and blue-green algae (1 species) (Fig. 6). A similar trend of species richness (S) was observed during the pre-bloom as well as peak bloom period. Of the 32 diatom species identified, 11 species were recorded during the pre-bloom, 9 species during the bloom phases, while 5 species were recorded during the post-bloom period. Similarly, of the 21 dinoflagellates species recorded, 14 species were observed during the pre-bloom and bloom periods and 11 species during the post-bloom period. The Shannon Weiner diversity index (H') was lowest during the bloom phase [H'(log2) = 3.37], while the pre-bloom phase recorded highest value [H'(log 2) = 2.55]. During the pre-bloom phase, *O. magnificus* rapidly started proliferating and reached peak abundance leading to the bloom and almost displaced the diatom population as this dinoflagellates are adapted to survive and thrive well in low nutrient conditions. This was followed by a sudden decline in the abundance of *O. magnificus* (post-bloom phase) due to the sudden drop in salinity from 35 to 32 PSU respectively as a result of the unexpected rainfall (7.53 mm).

During the pre-bloom and bloom periods, *Coscinodiscus* spp. dominated among diatoms, followed by *Hemiaulus hauckii, Surirella* spp., *Biddulphia mobiliensis* and *Navicula* spp. Among the dinoflagellate community, *Ornithocercus magnificus* was dominant followed by *Dinophysis miles, Protoperidinium* spp., *Ceratium furca, Ceratium tripos, Dinophysis caudata* and *Pyrophacus* spp. The post-bloom phase was notable for the presence of *Trichodesmium* spp. indicating a state of extended stratified condition.

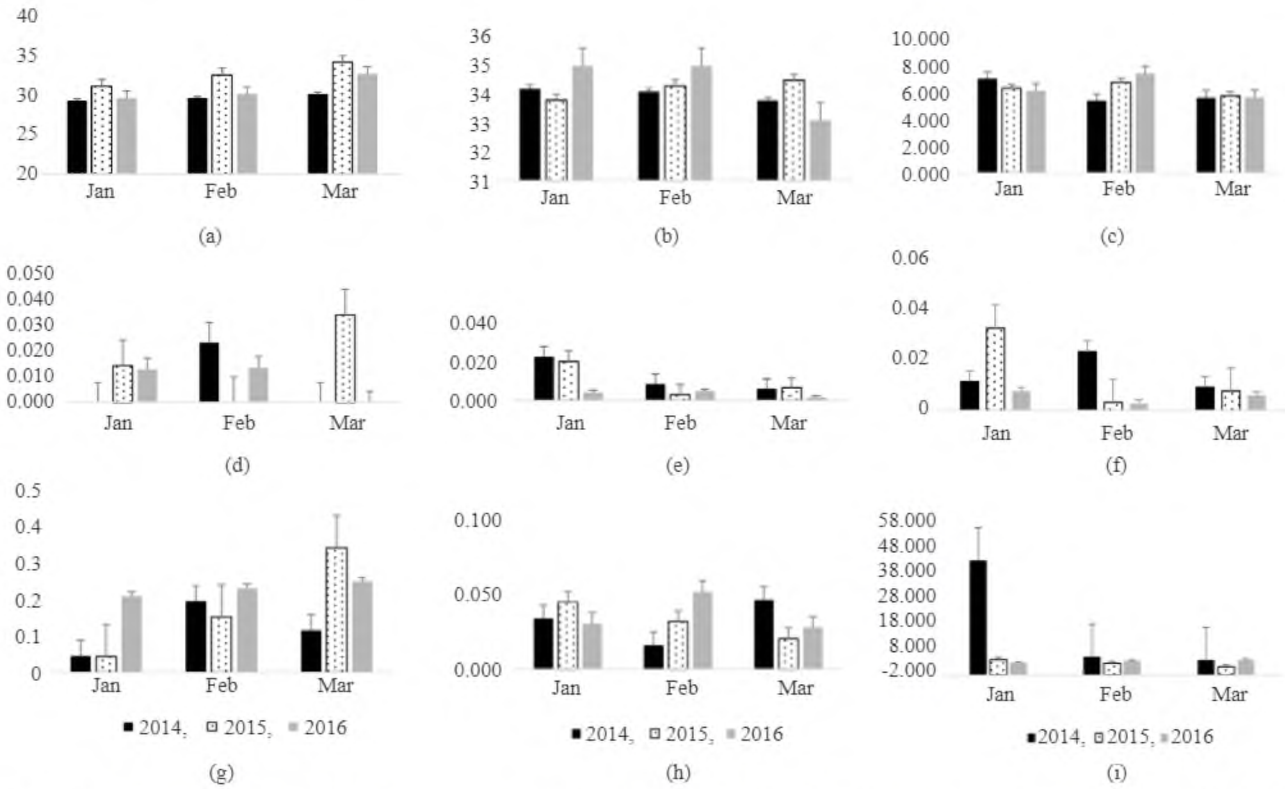


Fig. 4. Variations in the physio-chemical parameters of the nearshore waters off Dakshina Kannada during January-March of 2014-2016. (a) Seasurface temperature (SST (^{0}C), (b) Salinity (PSU), (c) Dissolved oxygen (DO mg l^{-1}), (d) Ammonia (mg l^{-1}), (e) Nitrite (mg l^{-1}), (f) Nitrate (mg l^{-1}), (g) Silicate (mg l^{-1}), (h) Phosphate (mg l^{-1}) and (i) Chlorophlla (Chl a, mg m^{-3})

Ectosymbiont bearing O. magnificus

Microscopic examination (40x) of the preserved individuals of *O. magnificus* (Fig. 7a,b) revealed the presence of ectosymbionts, possibly cyanobacteria in the cingulum as phaesosomes of some cells (3%) along with some remnants that resembled the ectosymbiont, in their food vacuoles. Similar observation of ectosymbionts was reported by Jyothibabu *et al.* (2006); Farnelid *et al.* (2010) and Tarangkoon *et al.* (2010),, in live specimens of *O. magnificus*. (Fig. 7a,b). Further detailed examination by transmission electron microscopy (TEM) as done by Lucas (1991); Farnelid *et al.* (2010) and Tarangkoon *et al.* (2010) could not be carried out during the present investigation.

Heterotrophic dinoflagellates like *O. magnificus* that lack photosynthetic pigments, are known to exclusively feed through osmotrophy (Droop, 1974). However, they have been observed to provide favourable microenvironments for free floating cyanobacteria, for efficient nitrogen fixation when the upper euphotic waters are stratified and the water masses become nitrogen limited (Gordon *et al.*, 1994; Jyothibabu *et al.*,

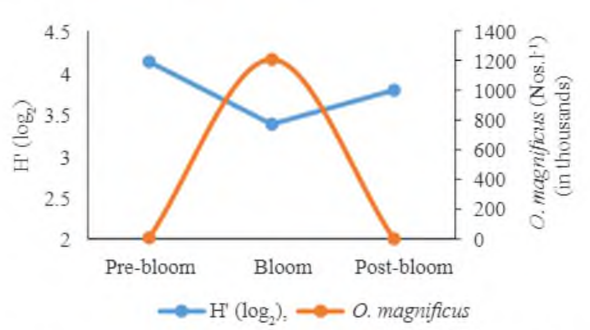


Fig. 5. *O. magnificus* abundance along the nearshore waters off Dakshina Kannada during the bloom

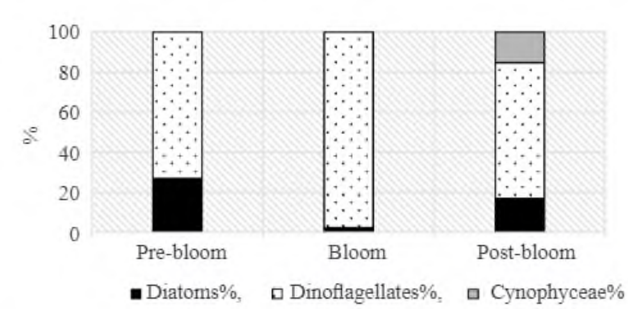
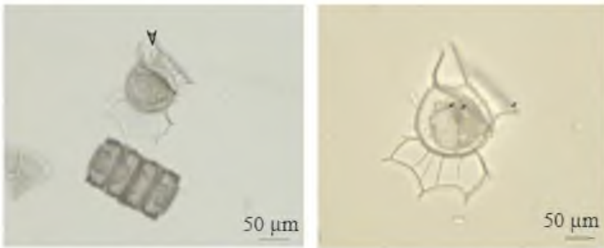


Fig. 6. Phytoplankton composition during the three phases of the bloom along the nearshore waters off Dakhsina Kannada



(a) (b)

Fig. 7. Light microscopy of preserved cells of *O. magnificus* showing (a) Ectosymbionts in the cingulum (arrow head) and (b) Enlarged view showing the presence of ectosymbionts in the food vacuoles (arrows)

2006; Farnelid *et al.,* 2010 and Tarangkoon *et al.,* 2010). Although *Trichodesmium* sp. plays a major role in the nitrogen cycling of the Arabian Sea, their abundance got higher only during the extended stratified conditions in post-bloom phase. During the initial stages of thermal stratification, the primary productivity is contributed by the free floating minute cyanobacteria (Li *et al.,* 1995; Maranon *et al.,* 2003; Jyothibabu *et al.,* 2006). The stable chlorophyll a and dissolved oxygen concentrations ($r_s = 0.985$, $p<0.001$) observed could be attributed to the presence of the ectosymbionts, resembling cyanobacteria enabling the host dinoflagellate to survive in oligotrophic waters through mixotrophy. The phaesosomes also have an advantage harbouring these dinoflagellates as they get protected from high oxygenated waters that can inactivate their N2 fixing nitrogenase enzyme activity (Paerl *et al.,* 1987; Jyothibabu *et al.,* 2006).

O. magnificus surface blooms and its possible link to high SST

Phytoplankton are ideal indicators of any sudden environmental perturbations as they have a high turnover rate and immediate biological response (Racault *et al.,* 2017). The SST along the west coast of India, normally shows a double oscillation. The first maximum is during the pre-monsoon months (April-May) and the second maximum during the beginning of post-monsoon season (Subrahmanyan, 1959). Similar trend was also observed in the salinity distributions along this coast. Under normal conditions, by the end of the pre-monsoon season, the dry winds push the warmer surface waters from the coast and bring in the deeper, cold nutrient rich waters upward, leading to coastal upwelling. But during strong El Niño events, these strong winds weakens and fails to displace the existing warm waters which gets transported as Kelvin waves leading to a delay in the coastal upwelling, resulting in thermal stratification and oligotrophic conditions (John *et al.,* 2018)

The present report on the bloom of *O. magnificus* that occurred during El Nino years is similar to earlier reports on its incidence along the SEAS. Impacts of El Nino, especially on primary productivity and phytoplankton populations have been found to be greatest in the tropical and subtropical regions of the world. Furthermore, the 2015/2016 El Nino as in the case of the present bloom incidence, happened to be one of the strongest and super El Nino event (Weare 1979; Saji *et al.,* 1999; Bo Lu *et al.,* 2018) in the 20th century breaking the warming record in the central Pacific, reaching its peak of 3°C in November 2015, represented by the NINO3.4 and NINO4 indices, after the 1982/83 and 1997/98 events. According to Saji *et al.* (1999) and Bo *et al.* (2017), the Indian Ocean SST during pre-monsoon months of 2016, was passively modulated by this 2015/2016 super El Nino leading to excess warming up of the Indian Ocean. This modulation led to positive SST anomalies in both western and eastern IOD (Indian Ocean Dipole) during January to April 2016 (Fig. 8). Kripa *et al.* (2018), also have reported a noticeable 1.1°C increase in the average SST from 28.6°C, in the sardine habitats off Kochi waters during 2015/2016 El Nino event. The tropical Indian Ocean also was dominated by positive SST anomalies exceeding 0.6°C during this period. The ONI index was also highest during pre-bloom and bloom periods (2.1). In the present study, the SST of pre-monsoon season of 2015 and 2016 was also observed to be higher as compared to 2014 (Fig. 4).

Warm waters with higher salinity are reported to be conducive for the growth of dinoflagellates (David *et al.,* 1960; Dae *et al.,* 2004). In the present study, *O. magnificus* abundance showed highly significant positive correlation with ONI index ($r_s = 0.790$, $p<0.001$), significant correlation with salinity ($r_s = 0.689$, $p<0.05$) and dissolved oxygen values ($r_s = 0.713$, $p<0.05$) while it was negatively correlated with nitrate concentration ($r_s = -0.646$, $p<0.05$) (Table 1). ONI index was also found to be negatively correlated with chlorophyll a ($r_s = -0.688$, $p<0.05$). Though *O. magnificus* abundance did not show any direct correlation with SST, its significant correlation with ONI index attributes its tolerance to increasing SST. Ectosymbiont bearing *O. magnificus* was found to be abundant at temperature range of 16.5-30.1˚C in the upper 100 m water column of the Indian Ocean (Tarnagkoon *et al.,* 2010). The SST (30±1.31˚C) during the bloom period was higher than the range reported earlier. Syed *et al.* (2008) had observed maximum (16.47%) frequency of *O. magnificus* along the North Arabian Sea when the water temperature ranged between 23.04 and 28.2˚C. Surface salinity (35.0±0.91 PSU) was comparatively lower than that reported by Syed *et al.* (2008). The salinity during the pre-monsoon season ranged from 36.3 to 36.5 PSU. Such environmental conditions helped the ectosymbiont bearing dinoflagellates to exhibit mixotrophy which can be defined as the combined use of photosynthetic and

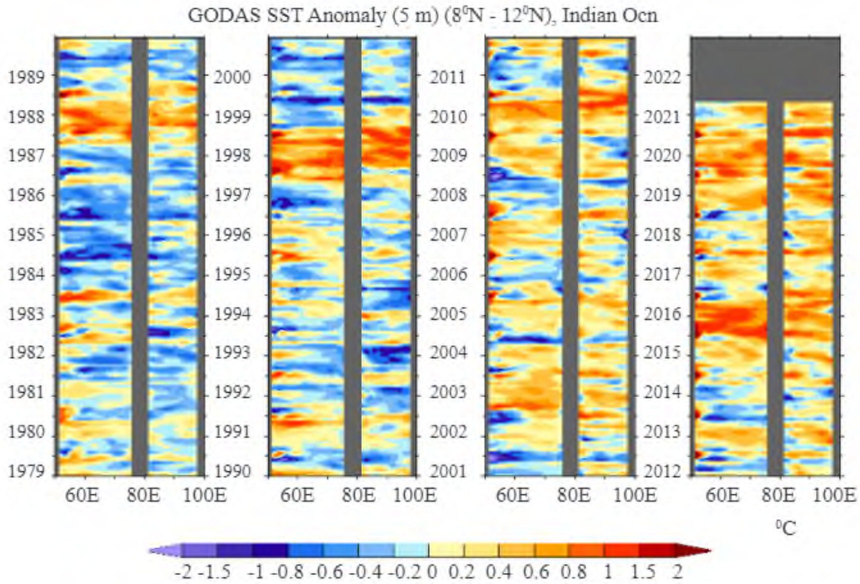


Fig. 8. SST anomalies in the Indian Ocean over the period from 1989-2021 (http://www.cpc.ncep.noaa.gov/products /GODAS/)

Table 1. Correlation matrix for the physico chemical parameters influencing the bloom of *O. magnificus* off Dakhina Kannada

			Air Temp	SST	pH	Salinity	Silicate	Phosphate	Nitrate	Ammonia	Dissolved Oxygen	Chla	ONI Index	*O. magnificus*
Spearman's rho	Air Temp	Correlation Coefficient	1.000	.692*	-087	.439	.549	-.102	-.075	-.370	-.146	.307	.150	.222
		Sig. (2-tailed)		0.27	.812	.204	.100	.778	.836	.293	.687	.387	.679	.537
		N	10	10	10	10	10	10	10	10	10	10	10	10
	SST	Correlation Coefficient	.692*	1.000	.242	-.013	.383	-.028	-.229	-.385	-.034	.494	-.252	.080
		Sig. (2-tailed)	.0.27		.501	.973	.275	.939	.525	.272	.925	.147	.482	.826
		N	10	10	10	10	10	10	10	10	10	10	10	10
	pH	Correlation Coefficient	-.087	.242	1.00	-.790**	-.243	-.813**	.139	-.072	-.241	.379	-.711*	-.559
		Sig. (2-tailed)	.812	.501		.007	.498	.004	.702	.960	.485	.280	.021	.093
		N	10	10	10	10	10	10	10	10	10	10	10	10
	Salinity	Correlation Coefficient	.439	-.013	-.790**	1.000	.431	.471	-.184	.204	.272	-.229	.803**	.689*
		Sig. (2-tailed)	.204	.973	.007		.214	.170	.610	.571	.446	.524	.005	0.27
		N	10	10	10	10	10	10	10	10	10	10	10	10
	Phosphate	Correlation Coefficient	-.102	-.028	-.813**	.471	.183	1.000	-.096	.006	.227	-.264	.404	.360
		Sig. (2-tailed)	.778	.939	.004	.170	.613		.792	.987	.528	.461	.247	.307
		N	10	10	10	10	10	10	10	10	10	10	10	10
	Nitrate	Correlation Coefficient	-.275	-.229	.139	-.184	-.080	-.096	1.000	-.152	-.889**	.505	-.561	-.646
		Sig. (2-tailed)	.836	.525	.702	.610	.826	.792		.676	.001	.137	.092	0.44
		N	10	10	10	10	10	10	10	10	10	10	10	10
	Ammonia	Correlation Coefficient	-.370	-.385	-.018	.204	.293	.006	-.152	1.000	.368	-.405	.328	.104
		Sig. (2-tailed)	.293	.272	.960	.571	.412	.987	.676		.295	.246	.355	.776
		N	10	10	10	10	10	10	10	10	10	10	10	10
	Dissolved Oxygen	Correlation Coefficient	-.146	-.034	-.251	.272	-.098	.227	-.889**	.368	1.000	-.681	.694*	.713*
		Sig. (2-tailed)	.687	.925	.485	.446	.789	.528	.001	.295		.0.30	0.28	0.21
		N	10	10	10	10	10	10	10	10	10	10	10	10
	Chla	Correlation Coefficient	.307	.494	.379	-.229	.024	-.264	.505	-.405	-.681*	1.000	-.688*	-.250
		Sig. (2-tailed)	.387	.147	.280	.524	.947	.461	.137	.246	.030		0.28	.486
		N	10	10	10	10	10	10	10	10	10	10	10	10
	ONI Index	Correlation Coefficient	.150	-.252	-.711*	.803**	.169	.404	-.561	.328	.694*	-.668*	1.000	.790**
		Sig. (2-tailed)	.679	.482	.021	.005	.640	.247	.092	.355	.026	.028		.006
		N	10	10	10	10	10	10	10	10	10	10	10	10
	O. magnificus	Correlation Coefficient	.222	.080	-.559	.689*	-.018	.360	-.646*	.104	.713*	-.250	.790**	1.000
		Sig. (2-tailed)	.537	.826	.093	.027	.960	.307	.044	.776	.021	.486	.006	
		N	10	10	10	10	10	10	10	10	10	10	10	10

*Correlation is significant at the 0.05 level (2-tailed)
**Correlation is significant at the 0.01 level (2-tailed)

heterotrophic nutrition within a single organism (Kofoid and Skogsberg, 1928; Lucas, 1991; Gordon *et al.,* 1994, Jyothibabu *et al.*, 2006). This mode of nutrition helps these dinoflagellates to thrive in the oligotrophic conditions and to dominate over other phytoplankton communities. High surface salinity caused due to evaporation during the pre-monsoon phase coupled with warm oligotrophic waters, with the help of the ectosymbionts could have favoured the formation of *O. magnificus* bloom.

Significance of Ornithocercus sp. bloom in fisheries

Kagwade (1964), reported that among the 6 dinoflagellate species found in the gut of oilsardine, the monthly frequency of occurrence of *Ornithocercus* sp. ranged between, 6.6 and 28.5% during pre-monsoon months and post-monsoon months when SST and salinity in the Arabian Sea was maximum. Oilsardines are surface feeders and are usually exploited by purse-seines, cast net, boat-seines and surface gillnets operating at depths ranging from 1 to 5 m and by drift gillnets and pelagic trawlnets operating nearshore between 10-20 m depths. However, Dulkhed (1972) observed difference in the food composition of oilsardine caught by gillnets and trawl nets operating along Dakshina Kannada during the pre-monsoon season. Oilsardine from the surface waters showed poor feeding and the diet mainly consisted of *Coscinodiscus* spp. while, sardines caught from the bottom waters had gorged stomachs and the diet mainly (97%) comprised of bottom dwelling *Ornithocercus* sp. Coincidently, this report based on the study made during 1963-64 also happened to be an El Nino year. Tasaduq *et al.* (2019) also observed the presence of *Ornithocercus* sp. as one of the main food of oilsardine caught using trawlnets during the pre-monsoon season during 2010-12 along the Ratnagiri coast, off Maharashtra. These reports clearly indicated that the Indian oilsardine occasionally foraged heavily on *Ornithocercus* sp., by moving to the bottom waters during the pre-monsoon seasons. When Kelvin waves lower the thermocline and brings a situation where the bottom waters becomes warm, a favourable environment is created for the temperature tolerant species like *Ornithocercus* sp. which proliferate with the help of its ectosymbionts and finally outnumber other phytoplankton species. The visualisation of depth-wise temperature anomalies of 2015-2016 El Nino event from January 2015 to December 2016, published by NASA (National Aeronautics and Space Administration) clearly depicts the temperature anomalies during the bloom period (Fig. 9). This visualisation also confirmed the warming of the bottom waters during the beginning of the bloom event. These events in turn impacted the feeding habits of oilsardine which usually migrate to the bottom waters for feeding during this season.

A decline in oilsardine catch during El Nino events has been reported by Rohit *et al.* (2018) and Shetye *et al.* (2019). They observed a collapse in oilsardine fishery from 1.55 lakh t in 2014 to 0.46 lakh t during the strong 2015-16 El Nino event along the Kerala coast. The catch recovered (1.27 lakh t) in the following year (2017), which was a normal ENSO (El Nino-Southern Oscillation) year. The 2015-16 El Nino event had a negative impact on the oilsardine fishery, which in turn resulted in high SST and reduced upwelling velocity, leading to minimum cooling of the surface waters and thereby favouring the dominance of nano and pico phytoplankton. A similar situation was observed along the coast of Karnataka, where the oilsardine fishery dropped down from 1.43 lakh t (2014) to 0.29 lakh t in 2015 and 0.27 lakh t in 2016 (Fig. 10.) In addition to the decline in catch Rohit *et al.* (2018) also reported on several changes in biological (growth and reproductive behaviour) and distribution patterns of oilsardines along the SEAS during the period.

The present study depicts the bloom dynamics of *O. magnificus* in relation to water quality, phytoplankton ecology and fishery (especially oilsardine fishery) of nearshore waters off Dakshina Kannada. The unusual increase in the dinoflagellate population density was in response to the El Nino induced high-temperature and high-saline and nutrient deficient (Nitrogen limited) conditions which were favourable for the growth of mixotrpohic *Ornithocercus* sp. Changes in the dinoflagellate composition with the dominance of *Ornithocercus* sp. at high densities and its relation to

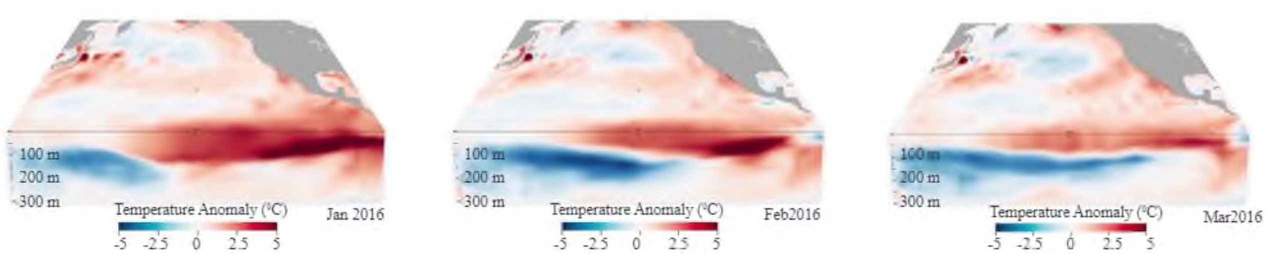


Fig. 9. Temperature anomalies in the ocean depths during the pre-bloom, bloom and post-bloom periods (by Joshua Stevens, using data from the Global Data and Assimilation Office (https://earthobservatory.nasa.gov/features/ElNino)

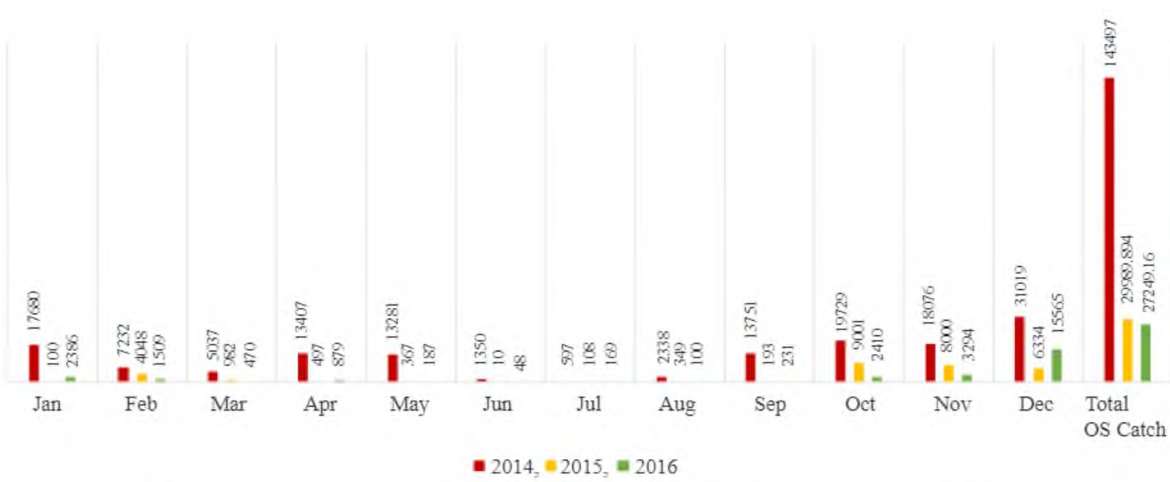


Fig. 10. Monthly and annual catch (t) of oilsardine for Karnataka during 2014-2016 (Source: NMFDC, ICAR-CMFRI, Kochi)

increasing SST have been reported along the coastal waters off Korean Peninsula (Kim *et al.,* 2008; Kim *et al.,* 2013) and from off Kochi coastal waters (Lavanya *et al.,* 2020). The present bloom lasted for a month (peak abundance observed 17 days from pre-bloom phase) and caused notable changes in the water quality and phytoplankton composition. Although there was no fish mortality corresponding to the bloom event, such frequent occurrence of a rarely blooming species in the surface waters and its link to the El Nino and warmer waters indicates visible changes in the marine ecosystem. Hence, warm and high saline waters induced by strong El Nino, creates oligotrophic conditions and delayed upwelling along the SEAS, thereby favouring the dominance of dinoflagellates like *O. magnificus* in association with ectosymbionts over other phytoplankton species. As surface feeders like oilsardine depends on these dinoflagellates for food during the warm seasons, surface blooms of this species need to be monitored and reported.

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