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Study of ecological consequence of the bloom (*Noctiluca miliaris*) in off shore waters of the Northern Arabian Sea

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Ship based observations during early March 2007 in oceanic waters of the Northeastern Arabian Sea followed by phytoplankton analysis indicated that the bloom *Noctiluca miliaris*, species of dinoflagellate, dominated oceanic waters of the basin during winter. Dark green discoloration was observed during February-early March. During the cruise FORV SS-212 *Sagar Sampada* in February-March 2003, surface water samples measured 64–4128 cells.l^{-1} and deeper layers (10-15 m) supported 1080-2542 cells.l^{-1} of *Noctiluca*. Chlorophyll concentrations were in a range 0.4-2.0 mg.m^{-3}, which reflect unusually high primary production in the deep waters (>2000 m). A pattern of zooplankton showed unusually high growth in the bloom waters. Fish catch data (% hooking rates of tuna) were obtained from Fishery Survey of India and were used to study response of fish to prevailing high productivity in the bloom waters. Fishing in oceanic waters within Indian EEZ indicated no adverse effect of bloom; rather remarkably higher catches resulted from long line operations in the bloom waters. Space-time variability in dissolved oxygen was studied to explain the observed preference of fish in the bloom waters.

[**Keywords:** Phytoplankton, Chlorophyll, Oxygen, Bloom, Zooplankton]

Introduction

Phytoplankton, also known as micro-algae, play an important role as primary producers in all marine habitats and form a base of marine food chain. It is noticed that bloom, *Noctiluca miliaris/scintillans*[1], occurs in the Northern Arabian Sea (NAS) during winter (December/January-March). Cooling of surface waters due to evaporation caused by prevailing cool, dry northeasterly winds results in increase in density and convection[2-5]. As a result, higher amount of nutrients arrive in the upper ocean, which enhances primary productivity[6].

Noctiluca miliaris also referred to, as *Noctiluca scintillans* is a marine planktonic dinoflagellate species. *Noctiluca* cells are unarmored, large (varies from 200-2000 microns in diameter), and spherical in shape with a single flagellum. They are intensely bioluminescent, cosmopolitan species with worldwide distribution in tropical and temperate waters. Colourless cytoplasm and absence of chloroplasts makes this species a non-photosynthetic heterotroph. *Noctiluca* is a phagotrophic and feeds upon other phytoplankton mainly diatoms[7].

Noctiluca miliaris is strongly buoyant and bloom forming species. *N. miliaris* red tides are commonly encountered in coastal and near shore regions of the world resulting in a pinkish red or orange discoloration of the water. Though the *Noctiluca* cells are colourless and non-photosynthetic on its own, the pink or red colour is attributed to the ingested material by *Noctiluca* depending on the geographic location[8]. In tropical oceans, (Arabian Sea, Indonesia, Malaysia, Thailand, Manila Bay) *Noctiluca* cells harbor green motile flagellates. Presence of these endosymbionts, *Pedionomonas noctilucae* belonging to family prasinophyceae gives *Noctiluca* blooms green or lime green colour[9]. It influences vast area of the basin for at least three months and therefore, study of its influence on living marine organisms was considered important.

Present study consists the ecological consequence of the bloom on living organisms at higher trophic levels viz. primary consumers (zooplankton) and secondary consumers (fish). Fish mortality usually results if the bloom is harmful or toxic as a result of their bio-toxins. Even if the bloom is not toxic, it can cause fish mortality due to oxygen depletion. When the bloom decays dissolved oxygen in water is consumed, which creates oxygen-deficient condition (anoxia) and it can result in fish mortality. However, present study indicated that the bloom *Noctiluca miliaris* is non-toxic in Northeastern Arabian Sea (NEAS) deep waters.

Measurements taken during Joint Global Ocean Flux Studies (US-JGOFS) for the Arabian Sea were used to study pattern of primary productivity during winter and its influence on primary consumers. Increase in concentration of primary and secondary consumers was noticed in the deep waters of NEAS during bloom. Fish catch data (tuna, long line) obtained from Fishery Survey of India were used to understand distribution of fish in NEAS during the bloom season. It was found that tuna hooking rates were extreme on higher side as compared to the same in southern waters away from bloom.

Materials and Methods

The study area is within 16°-24°N and 60°-68°E and is shown in Figure 1. Sequential *in-situ* data on chlorophyll, primary productivity (C^{14}), zooplankton etc. were collected in NEAS with research vessels ORV *Sagar Kanya* and FORV *Sagar Sampada* during 2003-2009. US-JGOFS ship cruise data

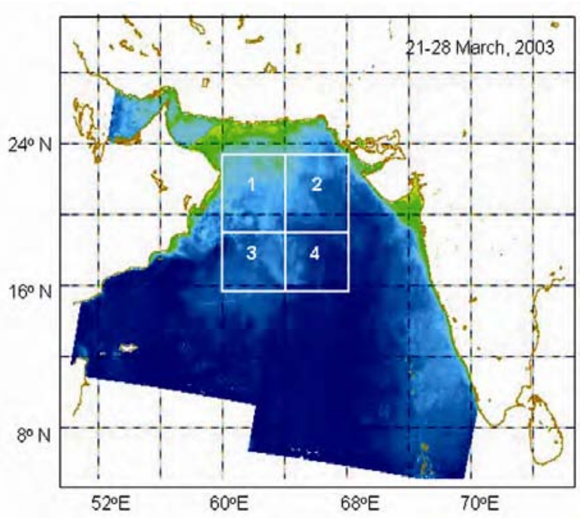

Figure 1—Study area 1. Active bloom area (19°-24° N, 60°-64° E) 2. Moderate bloom area (19°-24° N, 64°-68° E) 3. Moderate bloom area (16°-19° N, 60°-64°E) 4. Non-bloom area (16°-19° N, 64°-68° E).

(1995 Arabian Sea) were also used during the study. Fish catch data on percent hooking rate for tuna were collected by Fishery Survey India (FSI) for the period 2001 to 2005 as a part of their fishery survey programme and were used in this study. Chlorophyll images for the dates corresponding to fishing operation were generated using Oceansat I/OCM data to study the influence of increase in productivity on occurrence of tuna.

Based on chlorophyll pattern observed from weekly averaged image (Figure 1), the study area was divided in four parts.

i. Active bloom area (19°-24° N, 60°-64° E)
ii. Moderate bloom area (19°-24° N, 64°-68° E)
iii. Moderate bloom area (16°-19 ° N, 60°-64° E)
iv. Non-bloom area (16°-19° N, 64°-68 ° E)

Monthly average chlorophyll was computed from time-series daily OCM/chlorophyll images to study variability in chlorophyll pattern within the four demarcated areas (Figure 1). Daily chlorophyll images were generated from OCM data corresponding to the dates of fishing operations. This facilitated study of influence of bloom (increase in productivity) on primary and secondary consumers. Average of fish catch from the non-bloom area was considered as a reference to determine magnitude of changes occurring in concentration of tuna in response to the bloom. Fishing tracks were located on the respective chlorophyll images to observe correspondence of chlorophyll levels with availability (catch) of tunas.

Results and Discussion

Observations, from ship deck and laboratory on board

Several ship campaigns conducted in the past seven years (2003-2009) in the Northern Arabian Sea have revealed extensive bloom of green *N. miliaris* during February-March. *Rhizosolenia* spp and *Navicula* spp were found to dominant among diatoms along with *Noctiluca.* Zooplankton biomass in bloom stations was found to be quite high as compared to non-bloom stations. Water sample analysis revealed presence of large number of herbivorous and carnivorous zooplankton in the region indicating high bio-diversity. Fish eggs and fish larvae were also found in abundance indicating breeding season for many oceanic species. Major groups were copepods, copepodites, lucifers, oikopleura, chateognaths, dolilolum and amphipods etc. Colonies of salps were observed in large numbers in the bloom areas.

Schools of flying fishes and large size squids were observed during night at one bloom station in March 2007 (FORV-253). Also, on one occasion baby sharks were found swimming inside the bloom patch. These observations indicate that *N. miliaris* bloom in open ocean waters of Northeastern Arabian Sea is not having any adverse effect on the ecosystem.

The following observations were made from Figures 2(*a*) - 2(*d*).

Active bloom area (19°-24°N, 60°-64°E). During March 2002, chlorophyll-a concentration averaged over the bloom area from OCM data [Area 1 in Figure 2(*a*)] was 1.2 mg.m^{-3}. Average Zooplankton concentration was 54602 Cells.l^{-1} (Figure 2(*b*)). Fish catch data were not available for this area.

Moderate bloom area (19°-24°N, 64°-68°E). During March 2002, chlorophyll-a concentration measured 0.98 mg.m^{-3} averaged over moderate bloom area [Area 2 in Figure 2(*a*)], which is less than that from the Area 1 as mentioned above. Zooplankton data were not available for this area. Fish catch data from Fishery Survey India showed high Hooking rate (% HR) in this area (Figure 2(*d*)). It can be seen from

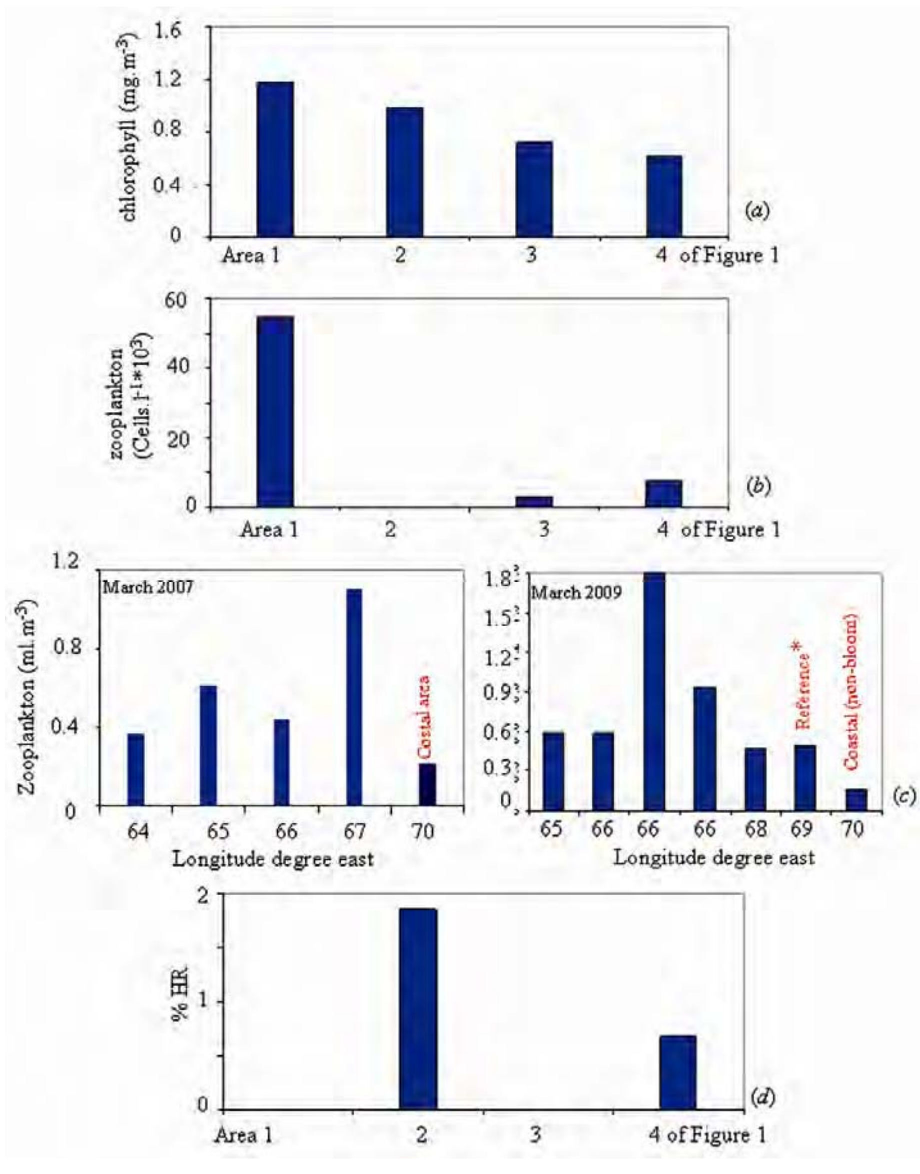

Figure 2—Inter comparison of primary, secondary and tertiary production in active (1), moderate (2, 3) and non-bloom area (4). Latitude: 21 – 220 N. (*a*) Monthly Average chlorophyll-a derived from OCM data (March 2002) (*b*) Average zooplankton from *in situ* data (14-19 March 1995 JGOFS) (*c*) Zooplankton from *in situ* data (March 2007, 2009 FORV Sagar Sampada) *Noctiluca* cell density = 9 Cells/20l of (*d*) % Average hooking rate of tuna (March-2001 to 2005).

table 1(*a*) that average hooking rate was 1.8% during February, March 2002, 2003 and 2005.

Moderate bloom area (16°-19°N, 60°-64°E). During March 1995, chlorophyll-a concentration averaged over this area was 0.71 $mg.m^{-3}$ (Area 3, see Figure 2(*a*)). Average zooplankton concentration was 2937 $Cells.l^{-1}$, which is significantly less as compared to that observed in the bloom area.

Non-bloom area (16°-19°N, 64°-68°E). Average chlorophyll computed from multi-date OCM/ chlorophyll images for this area was 0.61 $mg.m^{-3}$. This is lower than that found from the moderate bloom area (Area 4, Figure 2(*a*)). Average Zooplankton concentration was 7462 $Cells.l^{-1}$. Fish catch showed relatively lower hooking rate in this area. An average of 0.23% hooking rate was observed during February-March 2005 (Table 2).

March 2007: Zooplankton concentration was higher in moderate bloom area (Area 2, Figure 1) than in costal non-bloom area (Figure 2(*c*)). March 2009: Distribution of zooplankton across longitudes in Figure 2(*c*) indicates that zooplankton concentration was significantly higher compared to reference station away from bloom area in open and coastal waters.

In the open ocean (20°59' E, 66°11'N), Zooplankton concentration was 1.8 $mL.m^{-3}$ and *Noctiluca* cell density was 24×10^3 $cells.l^{-1}$. In the costal water, *N. miliaris* concentration was very less (density = 9cells/20l) and corresponding to this zooplankton concentration was also comparatively less (about 0.5 $mL.m^{-3}$).

From these preliminary observations it emerges that higher chlorophyll levels prevailing during the bloom help in development of zooplankton and the

Table 1—Fish catch data (from Area 2 in Figure 1) under influence of bloom

Sr. No.	Date	Latitude (Deg-Min)	Longitude (Deg-Min)	Hooking Rate (% Hr)	Average Hooking Rate
1	30-1-2002	20° 52' N	68°29'E	0.4	1.8
2	18-2-2002	20° 53'.5 N	68° 26'.5 E	3.75	
3	19-2-2002	21° 08'.5	68° 07' E	1.6	
4	20-2-2002	21° 09' N	67° 50'.5 E	0.9	
5	21-2-2002	20° 52'.5 N	67° 47'.5 E	0.9	
6	22-2-2002	21° 05'.5 N	68° 05' E	1.8	
7	23-2-2002	21° 27'.5 N	67° 38' E	1.4	
8	21-2-2003	21° 34' N	67° 32' E	0.6	
9	22-2-2003	21° 52'.5 N	67° 23' E	0.6	
10	25-2-2003	20° 49'.5 N	67° 13' E	0.4	
11	26-2-2003	20° 27' N	67° 41' E	0.4	
12	14-3-2003	20° 08'.5 N	68° 40'.5 E	4.48	
13	14-3-2003	20° 08'.3 N	68° 59'.5 E	0.72	
14	16-3-2003	20° 44'.5 N	68° 50' E	2.2	
15	17-3-2003	20° 27'.5 N	68° 07'.7 E	1.8	
16	18-3-2003	20° 15'.5 N	68° 08' E	3	
17	20-3-2003	19° 36' N	69° 11'.5 E	2.4	
18	22-3-2003	19° 17' N	69° 23' E	7.8	
19	19-3-2003	19° 34' N	68° 49' E	3.6	
20	21-3-2003	19° 36' N	68° 46' E	0.8	
21	23-3-2003	19° 23'.5 N	69° 13' E	3.2	
22	24-3-2003	19° 33' N	68° 49'.5 E	0.6	
23	28-3-2003	18° 51' N	69° 38' E	0.6	
24	25-3-2003	19° 50' N	69° 30'.5 E	0.6	
25	19-3-2005	19° 0'.75 N	69° 0'.25 E	0.8	
26	27-3-2005	19° 0'.5 N	69° 0'.25 E	1.2	
Fish catch data (from Area 2 in Figure 1) in April (Post-bloom period)					
1	09-4-2002	21° 24' N	67° 45' E	0.8	0.46
2	10-4-2002	21° 17' N	67° 33' E	0.2	
3	11-4-2002	21° 13 ' N	66° 48' E	0.6	
4	12-4-2002	21° 23 ' N	66° 45' E	0.32	
5	13-4-2002	20° 50 ' N	67° 43' E	0.64	
6	14-4-2002	20° 20 ' N	67° 53' E	0.32	
7	15-4-2002	19° 02 ' N	68° 12' E	0.32	
8	16-4-2002	20° 15 ' N	68° 17' E	0.64	

Table 2—Fish catch data for non-bloom area (Area 4 in Figure 5.1)

Sr. No.	Date	Latitude (Deg-Min)	Longitude (Deg-Min)	Hooking Rate (% Hr)	Average Hooking Rate	Std Dev
1	13/02/2005	16 ^{o} 59' N	70 ^{o} 33' E	0.16	0.23	0.10
2	14/02/2005	16 ^{o} 43' N	70 ^{o} 22' E	0.16		
3	25/03/2005	18 ^{o} 55' N	68 ^{o} 05' E	0.2		
4	27/03/2005	19 ^{o} 02' N	69 ^{o} 27' E	0.2		
5	21/02/2005	14 ^{o} 45' N	71 ^{o} 07' E	0.16		
6	24/02/2005	16 ^{o} 23' N	71 ^{o} 26' E	0.16		
7	21/03/2005	20 ^{o} 13' N	69 ^{o} 09' E	0.4		
8	22/03/2005	20 ^{o} 25' N	68 ^{o} 44' E	0.2		
9	23/03/2005	20 ^{o} 38' N	68 ^{o} 40' E	0.2		
10	24/03/2005	20 ^{o} 09' N	68 ^{o} 42' E	0.2		
11	15/02/2005	16 ^{o} 18' N	70 ^{o} 13' E	0.32		
12	19/02/2005	15 ^{o} 39' N	70 ^{o} 37' E	0.48		
13	28/03/2005	18 ^{o} 45' N	70 ^{o} 00' E	0.2		

fish concentration, both herbivorous and carnivorous. The area acts as feeding ground for all organisms in the food chain.

Impact of bloom on fishery

Active bloom area (Area 1, Figure 1) lies beyond the Indian EEZ and fishing operation was not carried out here. However, it can be seen from Figure 2(*d*) and Table 1(*a*) that average hooking rate (HR) of tunas is 1.8% from the moderate bloom waters (Area 2), which is significantly higher than the average value 0.23% from non-bloom waters (Area 4, Table 2). Fish catch data from the same area (Area 2) yielded comparatively less average catch of 0.46% HR during April (Table 1(*b*)), which is post-bloom season.

Fishing tracks of long line operations were located on chlorophyll images of respective dates. These are shown in figures 3(*a*)-(*g*) within a circle. Catch values (% HR) with respect to a number indicated next to the fishing track can be read from Table 1(*a*).

All the fishing tracks shown in Figures 3(*a*)-(*g*) are within the bloom affected waters and represent higher values compared to the catches observed from the non-bloom waters. Thus, high productivity during the bloom serves as feeding grounds and helps in development of food chain and consequently good catches of tunas. Fishing tracks from the non-bloom waters have been located on weekly averaged chlorophyll images as shown in Figure 4. Three fishing tracks 8, 10 and 11 (Table 2) are seen in low productivity area away from any frontal structure. Chlorophyll concentration in the off shore waters is less in the waters away from bloom and correspondingly reported catches are also poorer.

Observations of preference of tuna within the bloom waters can be made with the help of chlorophyll images in Figure 5(*a*). It can be seen that track 2 (Figure 3(*a*) and Table 1(*a*)), which yielded good catch of tuna (3.75%) is located in vicinity of periphery of cyclonic eddy. In comparison to this, track 9 (Figure 3(*c*) and Table 1(*a*)), found near a weak colour front and yielded relatively lower hooking rate (0.6%) though fishing was done in the same bloom environment. Thus, location of oceanic features like front, eddy etc. should be considered for profitable fishing even within the waters under influence of bloom[10-13]. Fishing in non-bloom waters resulted in comparatively poor catches (Figure 5(*b*)).

Pattern of dissolved oxygen

NEAS. It can be seen from Figure 6(*a*) that concentration of dissolved oxygen at surface increases from west to east. It is significantly higher (close to 5 mL/L) at 67° E in the NEAS even in March (1995 and 2007) when decay of bloom occurs. Generally, oxygen is consumed during the processes of respiration and degeneration. However, it appears from the pattern that this depletion of oxygen is not intense enough in the NEAS. This may be due to relatively moderate increase in primary production in the NEAS resulting in restrained decomposition of organic matter. Vertical profile in Figure 6(*b*) shows that oxygen content remains fairly high, ≈ 4.5 mL/L, up to 60 meters depth in January as well as March in the NEAS. For this reason; one can believe that the bloom does not cause damage to tuna fishery in NEAS waters. Rather, increase in productivity and development of associated food chain during the bloom provides feeding ground for tunas.

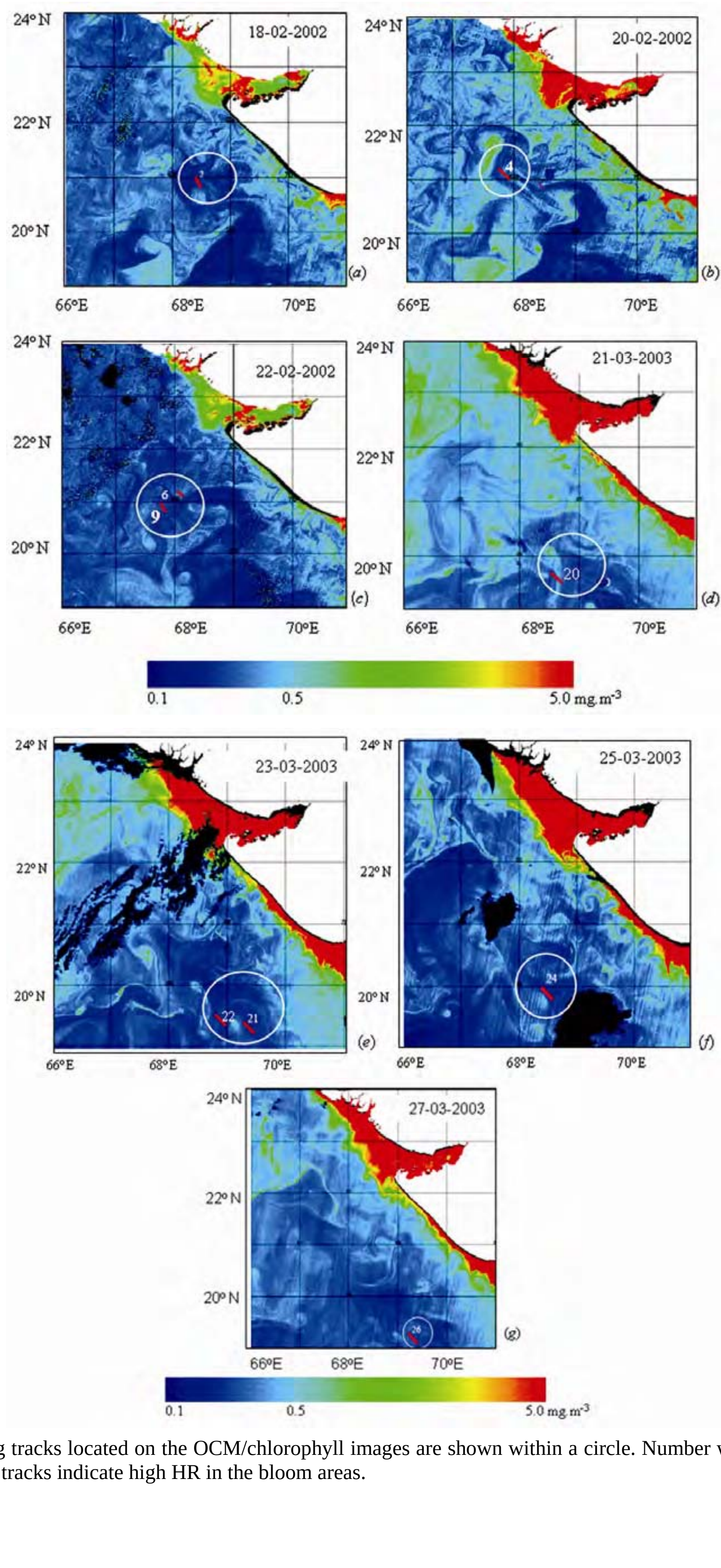

Figure 3—(*a*)-(*g*). Fishing tracks located on the OCM/chlorophyll images are shown within a circle. Number within the circle represents Sr. No. in Table 1. Fising tracks indicate high HR in the bloom areas.

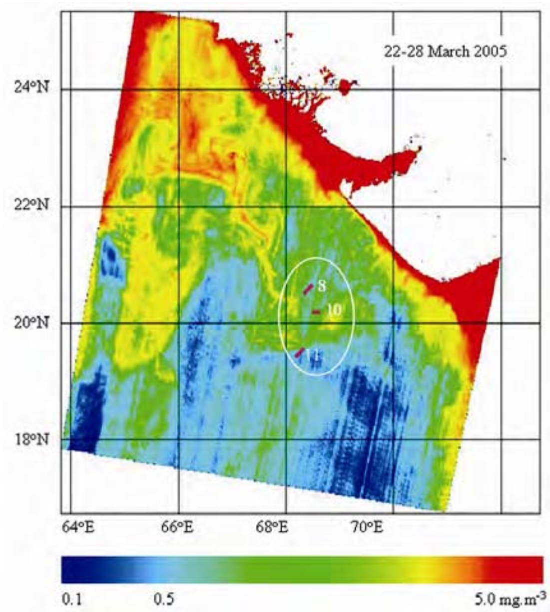

Figure 4—Fishing tracks located on the weekly averaged OCM/chlorophyll image are shown within a circle. Numbers within the circle represent Sr. No. in Table 2. Fishing tracks indicate low HR in the non-bloom areas.

NWAS. Unlike in NEAS, concentration of dissolved oxygen can be seen comparatively lower in NWAS (Northwestern Arabian Sea, Figure 6(*a*) at 60°E). Moreover, it is seen decreasing from January to March (decay phase).

The probable factors which may play a role in causing reduction in oxygen on the western side are described in the following sub-sections.

Degeneration of organic matter

Increase in productivity in the NWAS waters is found to be the highest during the bloom and occurs as early as in December/January. Resulting increased load of particulate organic matter could cause massive sedimentation where bacteria might decompose it consuming dissolved oxygen from the surrounding waters. It would create high demand for oxygen particularly during decay phase in March. Corresponding to higher production on the northwestern side, respiration is also expected to be more aggravating anoxic condition. In an environment like this, fish would be deprived of oxygen[14].

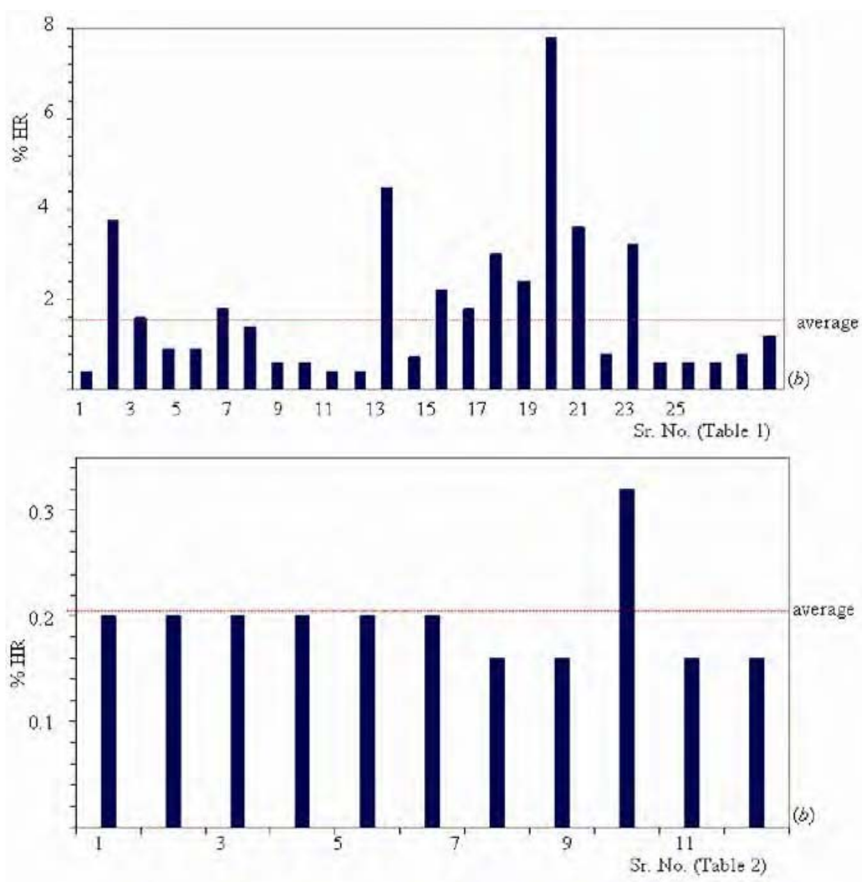

Figure 5—(*a*) %HR in bloom area (numbers on X-axis represents Sr. No. in Table 1). (*b*) %HR in non-bloom area (numbers on X-axis represents Sr. No. in Table 2).

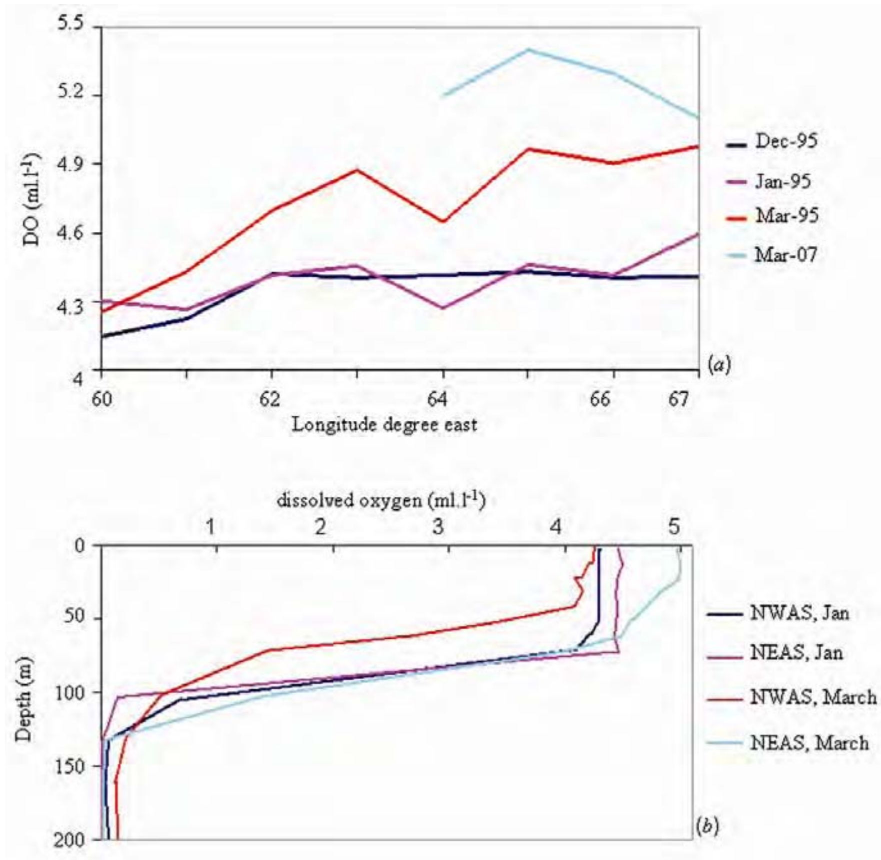

Figure 6—(*a*) Space-time variability in dissolved oxygen (surface) along zonal direction within 20°-22° N. (*b*) Vertical profile of dissolved oxygen for NWAS and NEAS during January and March (source: ship cruise US-JGOFS Arabian Sea (1995), SS-253 (2007)).

Convection-driven upwelling. Relatively more intense convection in the NWAS could be another factor for the observed depletion of oxygen. There is mention of fish mortality due to bloom forming dinoflagellate *Noctiluca Scintillans* in the Gulf of Oman[15]. Mortality of fish is attributed to the rapid increase in the population of *Noctiluca* and *Trichodesmium* during the months of June, January, and October.

Exact reasons have not been detailed for this adverse effect. However, it appears from the present study that oxygen concentration is less over all in the west (Figure 6(*a*) and 6(*b*)) during January as well as March. At times; when this might deplete substantially it could cause mortality of fish.

2009 anomaly. It was observed in February 2009 (Ship cruise SK-256) waters in the deep NEAS were dark green in colour (Chlorophyll concentration was 27 mg.m^{-3}). This is unusual and corresponding to this dissolved oxygen dropped significantly (Figure 7 (*a*)). This observation substantiates hypotheses that degradation of organic matter due to high production

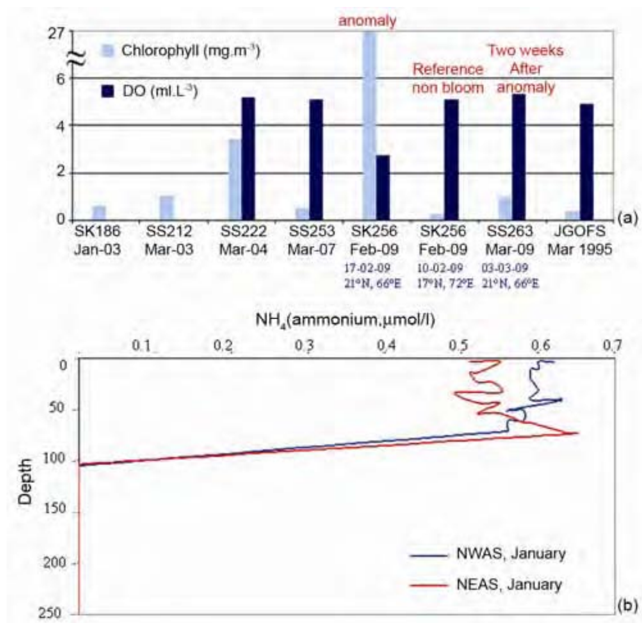

Figure 7—(*a*) Maximum chlorophyll and minimum dissolved oxygen during bloom, Cruise SK-256 (anomaly). (*b*) Ammonium concentration in January in NEAS during 1995 (JGOFS).

Table 3—Fish catch obtained with gill net fishing in the bloom waters during February-March 2008 and 2009 in off shore waters of the Northeastern Arabian Sea

Fishing Schedule	Location		Depth (M)	Total Catch (Kg)	CPUE Kg/Day
	Latitude (deg-min) N	Longitude (deg-min) E			
8-13/03/08	19 º 20' N	68 º 57' E	900	2700	450
8-17/02/08	21 º 12' N	68 º 45' E	750-800	2100	210
9-18/03/08	20 º 30' N	68 º 47' E	2500-3000	4250	420
11-18/02/08	20 º 12' N	69 º 10' E	900-1000	3300	412
Average CPUE for February-March 2008					373
12-23/02/09	20 º 08' N	69 º 00' E	1980	1105	100
09-23/02/09	19 º 09' N	69 º 04' E	2700	2400	171
Average CPUE for February-March 2009					136

rate tends to decrease concentration of dissolved oxygen.

Gillnet fishing: It can be seen from Table 3 that during February–March 2008 and 2009 total fish catch in bloom area was significantly higher catch per unit effort (CPUE) was observed during 2008 as compared to same in 2009.

Over all, fishing operations within bloom waters yielded consistently high tuna hooking rates. Catches declined when fishing was performed in the waters away from influence of the bloom. In addition to response of fish, the zooplankton communities, primary consumers dominated by copepods were found in abundance throughout the bloom. These observations indicate that the bloom is not harmful or repellent for tunas rather it is supportive. Drop in fish catch in 2009 may be attributed to decline oxygen level due to 2009 anomaly.

Distribution of ammonia (temporal and spatial variability)

Another reason for the reported adverse effect of bloom in the NWAS waters may be increased level of ammonia on this side due to excretion by organisms in the developing food chain and degradation of *Noctiluca* cells (Figure 7(*b*)). Ammonia is expected to accumulate in NWAS, as production is higher on this side. It can gradually reach a toxic level.

January 1995. It can be seen from table 4 that NH_4, NO_3 and normalized NH_4 uptake rates are higher in the NWAS as compared to it in the NEAS. This could generate unusually high productivity in the west. Decay of this high biomass is associated with increased level of NH_4. NH_4 concentration in March reflects this.

Though NH_4 concentration is relatively higher in the NWAS, its uptake rate normalized to concentration measured too low allowing NH_4 to accumulate (0.218 μmol/l). Instances when the increase dominates, it could have toxic effect on fish.

Table 4—Distribution of ammonia and nitrate during the bloom

January 1995		
	NWAS (22°N, 61°E)	NEAS (20 °N, 66° E)
NH_4 (μmol/l)	0.57	0.51
NO_3 (μmol/l)	3.73	3.11
N^{15} uptake rate for NH_4 (μmol/l/d)	1.1	0.975
N^{15} uptake rate for NO_3 (μmol/l/d)	0.21	0.032
NH_4 uptake/NH_4	1.93	1.91
	NWAS (22°N, 61°E)	NEAS (20°N, 66°E)
NH_4 (μmol/l)	0.218	0.03
NO_3 (μmol/l)	4.19	0.36
N^{15} uptake rate for NH_4 (μmol/l/d)	0.0058	0.0024
N^{15} uptake rate for NO_3 (μmol/l/d)	0.0108	0.0117
NH_4 uptake/NH_4	0.027	0.08
March 1995		

Conclusion

Winter planktonic bloom (*Noctiluca miliaris*) is found in the Northern western Arabian Sea. During bloom period increase in zooplankton concentration was observed in the entire east-west belt of the NAS. Collection of geo reference fish catch obtained through long line fishing in the bloom waters of NEAS indicate that there is no circumstantial fish mortality or fall in their catch. Moreover, it is found that there is sudden increase in the tuna catch in the months of January-March in the NEAS and can be attributed to the long duration of the massive bloom. The above observations suggest that the bloom is not harmful, rather supportive and eco friendly at least in the NEAS. Thus, this winter planktonic bloom is non-toxic bloom rather it supports the primary and secondary consumers.

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