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## SHORT COMMUNICATION

### Biomass and production characteristics of the first red tide noticed in Kuwait Bay, Arabian Gulf

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**Abstract.** Observations on the first red tide off Kuwait, Arabian Gulf, yielded high biomass [55.4–262.7  $\mu\text{g}$  chlorophyll (Chl)  $a\text{ l}^{-1}$ ] and primary production (507.9–571.2  $\mu\text{g C h}^{-1}\text{ l}^{-1}$ ), comparable with some of the highest values reported. There were contrasting changes in the carbon assimilation ratios, composition of the phytoplankton and the contribution of nanoplankton (<20  $\mu\text{m}$ ) between 11 and 12 May. On 11 May, carbon assimilation by nanoplankton was 2.2  $\mu\text{g C }(\mu\text{g Chl }a)^{-1}\text{ h}^{-1}$ , but increased to 9.2  $\mu\text{g C }(\mu\text{g Chl }a)^{-1}\text{ h}^{-1}$  the following day. Nanoplankton contributed 56 and 9% of Chl  $a$  and production, respectively, on 11 May, while net plankton (>20  $\mu\text{m}$ ) accounted for >65% of the biomass and primary production on 12 May. Picoplankton (<3  $\mu\text{m}$ ) contributed <8% of Chl  $a$  and <3% of production. Frequent sampling will be necessary to capture such dynamic changes and ephemeral events in these waters.

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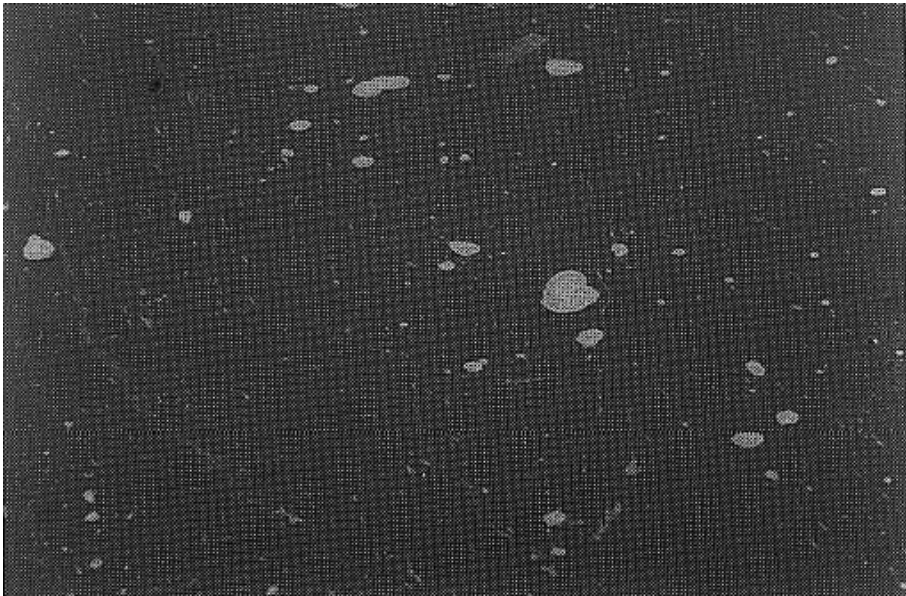
The first red-water report was from the rivers, canals and pools in Egypt, and dates back to biblical times (Bible, Exodus 7: 20–21). Although there has been a global increase in the incidence of red tides, only a few cursory reports exist from the Arabian Gulf (Green, 1986; Anonymous, 1996). In the Gulf, the ephemeral red tides have escaped attention probably by default. Off Kuwait, blooms of the haptophyte *Phaeocystis* sp. (Al-Hasan *et al.*, 1990; Al-Yamani *et al.*, 1997) and the ciliate *Mesodinium rubrum* (Al-Yamani *et al.*, 1997) were noted. We report here the first discoloration of surface water during 11 and 12 May 1997 off Kuwait. Changes in the qualitative and quantitative abundance of phytoplankton, biomass and production characteristics during the red tide were drastic, which suggests the dynamic nature of these waters.

A Sea Bird electronics profiler was deployed in and outside the patch (in the vicinity of 47°58'E and 29°27'N) on 11 May 1997. Profiles of temperature, salinity, percentage saturation of dissolved oxygen, pH and chlorophyll (Chl) (a measure of algal biomass), were obtained. Biomass and production measurements are based on surface water samples. Size fractionation for picoplankton was with Nuclepore filters (<3  $\mu\text{m}$  retained on 0.4  $\mu\text{m}$ ) and for nanoplankton with a nitex screening tower (<20  $\mu\text{m}$  retained on 0.4  $\mu\text{m}$ ). Chlorophyll  $a$  determinations were on duplicate water samples using the fluorometric method (Strickland and Parsons, 1972). Pigments were extracted in 90% acetone, refrigerated at 0°C for 24 h, and were determined using a Turner Design fluorometer Model 10-AU.

Carbon uptake measurements were based on carbon-14 tracer technique (Steemann-Nielsen, 1952). Carbon-14 ( $[^{14}\text{C}]\text{HCO}_3$ ) was added to the seawater sample and mixed. Aliquots of this were added to 5 ml of liquid gold scintillation fluid and used for added activity determinations. Samples labeled with  $\text{NaHCO}_3$  were transferred to three light and one dark Pyrex bottles. These were incubated under natural light with a photosynthetic photon flux density of  $1160 \mu\text{mol m}^{-2} \text{s}^{-1}$  for 3 h in a 2 ton fiber glass tank. Kuwait Bay surface water circulated through this tank simulated *in situ* temperature. Following incubation, samples were fractionated for  $<3 \mu\text{m}$  and  $<20 \mu\text{m}$  size categories, and filtered through  $0.4 \mu\text{m}$  Nucleopore filters. Filters were fumigated over concentrated HCl for 15 min and transferred to vials containing 5 ml of scintillation fluid. Activities were determined using a Wallac 1400 Tm scintillation counter. Dark uptake was  $<10\%$  of the light and was ignored. Total carbon dioxide in the sea water was determined based on temperature, salinity, pH and alkalinity (Strickland and Parsons, 1972).

On 11 May, the patch was offshore ( $>1 \text{ km}$ ), mossy brownish green, a few thousand meters long and  $<10 \text{ m}$  wide, parallel to the coastline, but on the following day was replaced by several small patches close to the shore. The discolored surface water had aggregates or rafts of phytoplankton cells that resembled dirty brown–yellow patties,  $<15 \text{ cm}$  in diameter (Figure 1). These rafts were easily scooped out of the surface for examination. By 13 May 1997, there were no traces of a red tide. Associated with these patches were hundreds of goatfish, *Upeneus tragula*, locally known as Hamer, usually discarded by the fishermen.

That the water column is well mixed is evident from the nearly uniform values of temperature, salinity, pH and oxygen (Table I). There were no major



**Fig. 1.** Rafts of algae in the patch.

differences in these properties between the profiles taken either in or outside the patch. Photosynthetically active radiation (PAR) was high at 1 m and decreased exponentially with depth.

Maximum extractable chlorophyll was at the surface (500.7  $\mu\text{g Chl } a \text{ l}^{-1}$ ). Fluorescence profiles showed a subsurface maximum at ~5 m inside the patch and at ~3 m outside the patch (Table I). Chlorophyll *a* levels (Table II) ranged between 262.7 and 500.7  $\mu\text{g l}^{-1}$  on 11 May, 96% of which was due to algae >3  $\mu\text{m}$ . On 12 May, algal biomass was 55.4  $\mu\text{g Chl } a \text{ l}^{-1}$ , 92% of which was due to algae >3  $\mu\text{m}$  (Table II). The picoplankton contribution corresponded to <4 and 8% on 11 and 12 May, respectively (Table II). Outside the patch, their contribution was 19% on 11 May and 25% on 12 May.

Primary production (Table II) was high (571.2 and 507.9  $\mu\text{g C h}^{-1} \text{ l}^{-1}$ ), most of it by algae >20  $\mu\text{m}$ , i.e. 89% on 11 May and 66% on 12 May (Table II). The

**Table I.** Temperature, salinity, oxygen saturation, pH, chlorophyll *a* and photosynthetically active radiation inside and outside the patch. Maximum values and corresponding depths are also given

	Depth (m)	Temperature (°C)	Salinity (‰)	% O <sub>2</sub> sat.	pH	Chl <i>a</i> ( $\mu\text{g l}^{-1}$ )	PAR ( $\mu\text{mol m}^{-2} \text{ s}^{-1}$ )
Outside	May 11, 1997						
	1.1	23.18	37.86	72.13	8.55	9.08	1.22E+03
	19.4	22.12	38.26	66.76	8.60	8.64	6.49E-02
	Maximum and at depth (m)	23.24	38.26	72.66	8.59	14.89	1.30E+03
		1.1	19.2	1.8	18.7	2.7	1.1
Inside	May 11, 1997						
	1.0	23.20	37.84	73.28	8.61	9.98	1.54E+03
	19.4	21.65	38.52	64.38	8.62	9.98	1.33E-01
	Maximum and at depth (m)	23.21	38.53	73.40	8.63	16.2	1.54E+03
		2.2	18.9	1.8	15.4	4.7	1.0
Inside	May 12, 1997						
	1.1	23.43	37.79	76.01	8.60	9.53	3.91E+02
	6.4	23.21	37.83	74.85	8.61	10.42	2.65E+01
	Maximum and at depth (m)	23.43	37.84	81.50	8.63	6.63	3.95E+02
		1.1	6.4	3.8	3.7	3.9	1.1

**Table II.** Distribution of chlorophyll *a*, production and carbon assimilation ratios in the unfractionated, <3  $\mu\text{m}$ , >3  $\mu\text{m}$ , <20  $\mu\text{m}$  and >20  $\mu\text{m}$  size fractions on 11 and 12 May 1997

Date	Fraction $\mu\text{m}$	Mean Chl <i>a</i> ( $\mu\text{g l}^{-1}$ )	Mean production ( $\mu\text{g C l}^{-1} \text{ h}^{-1}$ ) (SD)	$\mu\text{g C } (\mu\text{g Chl } a)^{-1} \text{ h}^{-1}$ (SD)
11	whole	262.7	571.2 (42.7)	2.2 (0.2)
	>3	252.2	560.8 (43.1)	2.2 (0.2)
	<3	10.5	10.4 (0.9)	1.0 (0.1)
	>20	105.2	509.8 (44.5)	4.8 (0.4)
	<20	157.5	61.4 (2.3)	0.4 (0.01)
12	whole	55.4	507.9 (25.8)	9.2 (0.5)
	>3	51.2	496.9 (25.8)	9.7 (0.5)
	<3	4.2	11.0 (0.5)	2.6 (0.1)
	>20	36.9	332.9 (27.0)	9.0 (0.7)
	<20	18.5	175.0 (3.0)	9.5 (0.2)

contribution of nanoplankton was 9 and 32% on 11 and 12 May, respectively (Table II). Picoplankton contributed ~2% to primary production.

Carbon assimilation ratios in the unfractionated samples on 11 May were  $<2.2 \mu\text{g C} (\mu\text{g Chl } a)^{-1} \text{ h}^{-1}$ , rather low compared to the  $9.2 \mu\text{g C} (\mu\text{g Chl } a)^{-1} \text{ h}^{-1}$  of 12 May (Table II). On both days, photosynthetic rates were similar in the  $>3 \mu\text{m}$  and the unfractionated samples. However, on 11 May, these rates for algae  $>20 \mu\text{m}$  were twice that of the whole sample. Picoplankton carbon assimilation rates ranged between  $0.99$  and  $2.6 \mu\text{g C} (\mu\text{g Chl } a)^{-1} \text{ h}^{-1}$ .

Algal biomass and primary production during this red tide were some of the highest values reported from tropical and subtropical bays. The present range of Chl *a* was higher than values reported earlier off Kuwait, i.e.  $135.9 \mu\text{g Chl } a \text{ l}^{-1}$  (Jacob *et al.*, 1979) or  $160 \mu\text{g Chl } a \text{ l}^{-1}$  from a bloom of *M.rubrum* (Al-Yamani *et al.*, 1997). Biomass values approximate those ( $120$  and  $550 \mu\text{g Chl } a \text{ l}^{-1}$ ) in the red-tide patches of *Gyrodinium instriatum* in the inner estuary of the Gulf of Guayaquil, Ecuador (Jimenez, 1993). Primary production in the present bloom was higher than the  $50 \mu\text{g C h}^{-1} \text{ l}^{-1}$  reported on a red tide bloom in the tropical St Helena Bay (Walker and Pitcher, 1991). Assuming a daily 12 h of sunshine, the calculated daily production of the local red tide ranged between  $6094$  and  $6855 \mu\text{g C day}^{-1} \text{ l}^{-1}$ , much higher than the photosynthetic rate ( $2342 \mu\text{g C day}^{-1} \text{ l}^{-1}$ ), on the red-tide ciliate *M.rubrum* in Mejillones sel Sur Bay (Marin *et al.*, 1993). Our values are comparable to the highest reported, i.e.  $5000$ – $15\,000 \mu\text{g C day}^{-1} \text{ l}^{-1}$  from the red tide patches of *G.instriatum* in the Gulf of Guayaquil (Jimenez, 1993).

The low carbon assimilation ratios on 11 May are comparable to the  $<3 \mu\text{g C} (\mu\text{g Chl } a)^{-1} \text{ h}^{-1}$  typical of natural blooms of the toxigenic diatom *Pseudonitzschia multiseries* in Cardigan Bay, Eastern Canada (Subba Rao *et al.*, 1988), or the toxigenic subsurface bloom of the dinoflagellate *Dinophysis norvegica* in Bedford Basin, eastern Canada (Subba Rao and Pan, 1993). Their sudden increase to the substantially high  $>9 \mu\text{g C} (\mu\text{g Chl } a)^{-1} \text{ h}^{-1}$  on 12 May is of interest. Such values are characteristic of exponentially growing cultures of *Thalassiosira rotula*, *Phaeodactylum tricorutum*, *Amphiprora kufferathii*, *Biddulphia aurita* and *Prochloron* sp. (see Subba Rao and Pan, 1995). Abrupt changes in the carbon assimilation ratios are possible with a replacement of the dominants in the phytoplankton assemblages. In the Bedford Basin, a red water bloom, dominated by the dinoflagellate *Gonyaulax digitale*, had a low carbon assimilation ratio of  $3.16 [\mu\text{g C} (\mu\text{g Chl } a)^{-1} \text{ h}^{-1}]$  in the initial stages, but the photosynthetic rate increased to  $6.20 [\mu\text{g C} (\mu\text{g Chl } a)^{-1} \text{ h}^{-1}]$  when replaced by small ( $3 \times 5 \mu\text{m}$ ) naviculoid diatoms (Amadi *et al.*, 1992). On a daily basis, an order of magnitude variation in the standing crop and primary production was observed in Barataria estuary, Louisiana (Shaffer and Sullivan, 1988). Displacement of benthic diatoms in these well-mixed shallow waters depended on wave height, meteorological tides and astronomical tides, and accounted for such short-term variations. Through frequent sampling over 36 h, Lizon *et al.* (1995) demonstrated large differences ( $-40$  to  $33\%$ ) in carbon assimilation ratios in a tidally well-mixed coastal shallow system of the eastern English Channel.

There were marked differences in the qualitative and quantitative abundance of phytoplankton between the samples collected 24 h apart. On 11 May, *Nitzschia* spp.

was the dominant ( $158 \times 10^6$  cells  $l^{-1}$ ), followed by gymnodinians ( $2.2 \times 10^6$  cells  $l^{-1}$ ). *Nitzschia* cells were 3.5–5  $\mu$ m wide and 85–102  $\mu$ m long. On the following day, their numbers corresponded to  $54.5 \times 10^6$  cells  $l^{-1}$  *Nitzschia* and 0.8 cells  $l^{-1}$  gymnodinians. Additionally, there were large numbers of pennate diatoms represented by unidentified species of *Diploneis*, and *Navicula*. On both days, picoplankton abundance was  $<4.5 \times 10^6$   $l^{-1}$  in the patch. Outside the patch, there were 45 000 cells  $l^{-1}$  each of *Nitzschia* spp., *Coscinodiscus* spp., *Hantzschia* spp., *Prorocentrum micans*, *Euglena* sp. and *Oxytoxum* sp. It is plausible that the hydrodynamics may have mediated these changes in the Kuwaiti Bay similar to those in the shallow tropical lagoon (Cote d'Ivoire) where wind-induced turbulence greatly influenced the distribution of bacteria, pico- and nanophytoplankton (Arfi and Bouvy, 1995). Compared to the picoplankton contribution of ~80% of total chlorophyll in the Red Sea and the Gulf of Aden (Gradinger *et al.*, 1992) and Hawaiian waters (Takahashi and Bienfang, 1983), its contribution during this bloom was small, i.e. <8% in the patch and <25% outside. Similarly, its contribution to production was also low as in the littoral tropical waters off Nosy-Be, Madagascar (Magazzu *et al.*, 1984).

It is of interest to note that microzooplankton comprising ciliates, nauplii, trochophore larvae and polychaete larvae were limited only to outside the patch. We speculate that the red water off Kuwait may have resulted due to: (i) reduction of the microzooplankton as in the 'brown tide' in the Laguna Madre of south Texas (Buskey and Stockwell, 1993); (ii) lack of microzooplankton grazing within the patch that bestowed a competitive advantage for the algae to develop into a red tide; or (iii) concentration of algae by a convection front. All these need to be substantiated.

While documenting the first red tide from Kuwait Bay, we suggest improving the frequency of our sampling for adequate description of biological events. The contrasting differences between the phytoplankton composition, abundance, magnitude of biomass, production and carbon assimilation ratios during a short term suggest the dynamic changes in our Gulf waters. In a shallow (<30 m) open bay with pronounced tidal amplitude (0.34–3.55 m on 11 May and 0.52–3.41 m on 12 May; Anonymous, 1997), stratification leading to gradual progression of a bloom is not possible. This probably explains why the ephemeral red tides escape observation in these waters. It is important to note that a potential exists for the occurrence of harmful algal blooms in these shallow subtropical waters with abundant solar energy, and reasonable levels of nutrients. Off Kuwait, *Asterionella glacialis*, *Chaetoceros coarctatus*, *Chaetoceros decipiens*, *Pseudonitzschia multiseries*, *Ceratium furca*, *Ceratium fusus*, *Ceratium trichoceros*, *Dinophysis caudata*, *Dinophysis norvegica*, *Dinophysis acuminata*, *Dinophysis acuta*, *Prorocentrum micans*, *Noctiluca miliaris*, *Phaeocystis pouchetii* and *Dictyocha speculum* algae, implicated elsewhere as harmful species, do occur. Thus, a need exists for a concerted effort with more frequent sampling to capture and document the red tides in the Gulf.

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