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Massive bloom of *Cochlodinium Polykrikoides* and its impacts in the United Arab Emirates' waters

Anbiah Rajan[1], Rajasekhar Thankamony[1], Yasser Othman[1], Shadab A Khan[2], Ebrahim A Jamali[3]
[1] Environment Quality Sector, Environment Agency, Abu Dhabi, United Arab Emirates
[2] Marine Environment and Wildlife Section, Dubai Municipality, Dubai, United Arab Emirates
[3] Marine Resources Research Centre, Ministry of Environment and Water, Umm Al Quwain, United Arab Emirates

Abstract
A prolonged bloom of *Cochlodinium polykrikoides* was observed from August 2008 to March 2009 in the United Arab Emirate's waters. This bloom was unique to the region in terms of its large spatial extent and impacts on the environment and economy. From its first detection in Fujairah, on the east coast of the country in the Gulf of Oman, the bloom moved anticlockwise around the coast, eventually reaching the west coast and the Iran coast to the north, without touching coastal Abu Dhabi in the Arabian Gulf. The bloom resulted in extensive mortalities of marine organisms including annelids, molluscs and fishes, both farmed and wild. The phytoplankton counts from multiple sites, meteorological data, water chemistry as well as information on the physical characteristics of the sampling sites, provided extensive spatial and temporal data sets. The bloom extended 1200 km of the coastline, lasted for more than eight months and killed an upwards of 600 tons of fishes. The cell numbers were as high as 1.3 x108 cells/L in the bloom area, and the water was slimy, foul-smelling and dark brown. The phytoplankton species composition and bloom durations significantly varied between sites. The hydrographic parameters and nutrient concentrations also varied between bloom and non-bloom areas. The dissolved oxygen concentration was very low (0.14 mg/L) and hypoxic conditions prevailed in the bloom areas. We integrated monitoring data with remote sensing to analyse the development and progression of the *Cochlodinium polykrikoides* bloom to further discuss its causes and impacts.

Keywords: algal bloom, *Cochlodinium Polykrikoides,* water quality, arabian gulf

Introduction

In recent years, the occurrence of harmful algal blooms (HABs) have been reported in many places of the Arabian Gulf than ever before, presumably due to the increased human activities and coastal development. This ultimately enhanced eutrophication, causing the algae to proliferate and disrupt ecological integrity.

The United Arab Emirates (UAE) is located at the southeast end of the Arabian Gulf. Saudi Arabia lies to the south and west, Oman to the north and east, and Qatar to the west. It has a coastline of 740 km, out of which 650 km is in the Arabian Gulf and 90 km in the Gulf of Oman. Its marine environment is under pressure from various human activities including offshore oil exploration, coastal dredging, land reclamation and urbanisation. UAE happened to be the victim to *Cochlodinium polykrikoides* bloom during the years 2008 and 2009.*C. polykrikoides* Margalef is an unarmoured chain forming mixotrophic dinoflagellate (Larsen and Sournia 1991; Jeong *et al*. 2004) [15, 10] capable of producing cysts. The species is one of the most noxious red tide producing harmful algae that can impact both the environment and economy worldwide (Yoon 2001; Kim *et al*. 2002; Matsuoka and Iwataki 2004; Suh *et al*. 2004; Miyahara *et al*. 2005; Imai *et al*. 2006) [30,12, 18, 87, 19, 9]. It was first described by Margalef (1961) [17] in Puerto Rico, in the Caribbean Sea. In Asia, *C. polykrikoides* is notorious for causing fish deaths in Japan (Kim *et al* 2002) [12], Korea (Yoon 2001) [30], China (Du *et al*. 1993) [4], the Philippines (Rolex and Bajarias 2003) [25] and Malaysia (Anton *et al*. 2006). In the US, *C. polykrikoides* blooms have been recorded by Gárate-Lizárraga, *et al*. (2000) [5] and Curtiss *et al*. (2008) [3].

To date, there has been no information on the cause and impact of *Cochlodinium* blooms in the Arabian Gulf, particularly in the UAE. The present paper aims to document the extensive bloom of *C. polykrikoides* along the UAE coast, as tracked by field observations and satellite data, including ocean colour (chlorophyll-a). This study discusses the nature of blooms including their occurrence, duration and movement in the UAE, and its impact on the ecology and economy.

Methods

Field investigations were conducted during and after the bloom, from various coastal waters of the UAE. During each visit, sampling of water and plankton from at least three sites were carried out from each bloom area. On 28 October 2008, the samplings were taken from the Fujairah area, inside and outside the Dibba Accamia (fishing port), Dibba Al Hassan (new fishing port) and the open sea. Subsequently, samplings were carried out on 17 November 2008 at Fujairah, from seven sites including the previous sampling sites such as inside and outside Dibba Accamia, Dibba Al Hassan (old and new fishing ports), Asamak fish culture area, Al Fakeet and near a desalination plant at Fujairah port.

During the first bloom (11 January 2009) in Dubai, the sampling was made at Port Rashid, followed by sampling on 14 January 2009 at three different sites, including Palm Deira. The second bloom in Dubai was investigated through a sampling carried out at four different sites (Table 1). However, the results discussed in

this paper have been limited to a few places where the results were not identical (Table 1).
At each sampling site, the basic water quality parameters, namely temperature, salinity, pH, dissolved oxygen and chlorophyll, were measured using the Hydrolab-Surveyor IV. Seawater samples were collected using a Niskin water sampler, and the nutrient analysis was conducted via an Auto Analyser (Skalar). Phytoplankton samples were collected through both bottle and net (20 microns), and cells were counted using a light microscope and identified with a scanning electron microscope at NOAA-USA. MODIS satellite imaging was used for estimating the concentration of chlorophyll in the coastal areas of UAE and track the bloom movement. Remote-sensing data were analysed at the Environment Agency – Abu Dhabi.

Results and Discussion

A colour change and several red patches in seawater were noticed at Kalba (25º00'.594''N, 56º21'.32''E) on 28 August 2008, and in Dibba Al Hassan at Fujairah coastal waters (25º36'592''N, 56º16'508''E) on 8 September 2008. Subsequently, incidences of fish deaths were reported frequently in various scales. A major incident occurred in October 2008, which continued and extended to other places in the country. The blooms were recorded in various places at different periods till October 2009, at various intensities (Table 1).
C. polykrikoides cells were present as single and four-cell zooids, and rarely eight and 16 cell chains. The distribution of the cells was recorded at 19 sites (Table 1). The abundance varied from 0 to1.3 x 108 cells/L (Port Rashid, Dubai). In Fujairah, the bloom occurred several times and extended over 55 km, whereas in Dubai the bloom was reported only twice, the first incident on 11 January 2009 at Port Rashid, on a smaller scale that covered less than 1 km and lasted for three days. However, the bloom intensity was extremely high and the cell concentration was 1.3 x 108 cells/L. The second bloom incident was reported on 2 April 2009, which extended from Palm Deira to Palm Jumeirah. It was comparatively larger and lasted for more than a week; however, no major fish mortality was reported.
With regards to temperature, the *C.polykrikoides* was found existing between 20.92°C and 28.53°C. During the bloom period, the water temperature at Fujairah varied from 26.79°C–28.53°C. Later, the bloom moved from the east coast to the west coast of UAE and appeared at Ras Al Khaimah, moving up to Palm Jumeirah, Dubai, during winter. The presence of bloom in different parts of the UAE during different temperature regimes revealed that the *C. polykrikoides* can tolerate a wide range of temperatures. Kudela *et al*. (2008) [14] reported the same and suggested that *C. polykrikoides* is an eurythermal organism.
In the UAE, the salinity of the *C. polykrikoides* population was recorded between 37.33 and 42.4 psu. The bloom initiated on the east coast with low salinity and extended to the west coast with high salinity (Table 1). Kim *et al*. (2001) [16] and Lee *et al*. (2001) [13, 16] reported that *C. polykrikoides* have wide tolerances for salinity (15–50 psu, with an optimum from 25 to 40 psu), and growth temperatures (10–30°C, with optimum growth at 25°C). In the Western Pacific, during a bloom incident, the water quality parameters showed a range of 18–30°C temperature and 30–35.8 psu salinity. Furthermore, Kudela *et al*. (2008) [14] suggested that this group is eurythermal and euryhaline and well adapted to warm waters. This corroborates with the present observation, from the bloom recorded in various parts of the UAE, during the different periods, that *C. polykrikoides* can tolerate a wide range of salinity and temperatures (Table 1).
The bloom areas showed pH variations between 7.63 and 8.56. The dissolved oxygen fluctuated between 0.14 and 9.68 mg/L, and the chlorophyll concentration during the bloom period varied between 0.01 and 52 µg/L, where the values were proportional to the bloom concentration (Table 1). The nutrient concentration in bloom areas showed higher values than normal seawater. The nitrite values fluctuated between 0.22 and 0.54 µM/L, and phosphate varied from 0.90 to 2.76 µM/L. The nitrate and silicate values oscillated between 0.32 and 0.81 µM/L and 1.58 and 4.99 µM/L, respectively. Kudela *et al*. (2008) [14] reported a lack of evidence in linking coastal eutrophication in the development of *Cochlodinium* blooms. This species has been recorded in both eutrophic (Park *et al*. 2005) [21] and non-eutrophic waters (Yoon *et al*. 2004) [29] and can tolerate a wide range of nutrient concentrations as well.
Recent studies evidenced that the *C. polykrikoides* can grow mixotrophically (Jeong *et al*. 2004) [10], and that this mechanism supports this phytoplankton in producing a red tide. They are also a strong vertical migratory species (Park *et al*. 2001) [22] and move along with the wind and current. The present investigation proved the same, and the influence of wind was evidenced in the patches of bloom found in the Fujairah fishing port – they were moving to and fro within a day along with the wind direction. The water current played a major role in the bloom movement. The satellite image analysis of chlorophyll (MODIS) from August 2008 to 2009 (Figure 2) indicated the progression of the bloom. When the bloom was correlated with the water currents (Reynolds, 1993) [26], it was apparent that the bloom movement was being controlled by the water current. The bloom started in the east coast of the UAE (Fujairah, in the Gulf of Oman) in August 2008, and moved anticlockwise, reaching the Arabian Gulf (Ras Al Khaimah, Sharjah and Dubai) in December 2008 and April 2009, after which the bloom moved along with the water current and reached the coast of Iran. Later, the bloom lost its intensity and disappeared in October 2009.
During the bloom period, the phytoplankton community structure in Fujairah varied between sampling sites. The areas with high *C. polykrikoides* density showed lesser number of species (Figure 1). Water samples collected from the bloom area on 28 October 2008 (Figure 1) showed no significant variation between the sites located in the bloom area, but the non-bloom areas showed an entirely different composition with a higher number of species and less concentration (Figure 1). The *C. polykrikoides* dominated the bloom area (> 90%), and it was followed by *Gymnodinium catenatum* (< 2.5%). The *G. catenatum* cells were recorded in all sampling sites (stations 1–4), and the concentration varied from 0.18% to 2.3% of the total population. The analysis of the samples collected on 17 November 2008 showed (Figure 1) different compositions. The *C. polykrikoides* population was drastically lower in stations 5 and 3 (25% and 0%, respectively), and marginally lower in sampling sites 7 and 8 (70.58% and 71.43%, respectively).
During the first bloom incident (11 January 2009) in Dubai, the sample (Figure 1) was filled with *C. polykrikoides* (100%). After three days, during the second sampling, the *C. polykrikoides* concentration was reduced to 67%. However, at the nearby area (Palm Deira-Corniche), the phytoplankton population structure

was different; the bloom sample was filled with only three species (Figure 1). Among them, *Prorocentrum minimum* was about 81.51%, and it was followed by *Psuedonitzschia* sp (12.3%) and *Prorocentrum* sp (6.19%). At station 3, the phytoplankton population was dominated by *P. minimum* (36.8%), followed by *Psuedonitzschia* sp (26.3%). Other species found in this area were *Thalassionema nitzschioides*, *Thalassiosira* sp, *Rhizosolenia styliformis*, *Skeletonema costatum*, *Prorocentrum* sp *and Astrerionellopsis* sp. During the second bloom on 2 April 2009, the *C. polykrikoides* population varied from 65.38% to 98.56%, along with the presence of 13 other phytoplankton species being recorded (Figure 1). However, the percentage was very low. In addition, station 1 was filled with *Noctiluca scintillans* (Table 1 and Figure1).

The *C. polykrikoides* bloom in the UAE waters caused depletion of dissolved oxygen, changes in phytoplankton abundance and species and closing of desalination plants. Furthermore, the bloom affected the tourism industry, distribution of corals and benthic organisms and produced multi-species fish deaths. During the bloom period, both in Fujairah and Dubai, the water quality parameters changed remarkably; on the whole, the dissolved oxygen concentration decreased and reached up to 0.14 mg/L in early morning hours and simultaneously, during noon, the values increased and reached a maximum of 9.68 mg/l. The hypoxic condition created by the bloom could be one of the reasons for the mortality of the fishes, particularly in the fish farms (ASAMAK). Approximately, 650 tons of multi-species wild and cultured fishes died in the UAE. Mass mortalities of marine organisms associated with the *C. polykrikoides* bloom was reported worldwide (Onoue and Nozawa 1989; Yuki and Yoshimatsu 1989; Guzman 1990; Kim 1999; Garate-Lizarraga *et al*. 2000; Whyte *et al*. 2001; Curtis *et al*. 2008). Besides this, Whyte *et al*. (2001) reported the mass mortality of cultured salmon on the west coast of Canada, and explained that mortality occurred because caged fish have lesser opportunities to avoid the impact of HABs than wild fish. In the UAE, the maximum mortality recorded was in fish farms, due to the limited opportunity to avoid low oxygen levels created by the bloom.

Guzmán *et al*. (1990) [7] stated that the blooms of *C. catenatum* were implicated in coral mortality in Costa Rica and Panama. Bauman *et al*. (2010) [2] reported that the coral reefs in the UAE were affected maximum, in terms of both species and functional compositions, due to the *C. polykrikoides* blooms. In addition to corals, the benthic organisms found in the bloom area were also reduced and dead organisms were found during the bloom period. The impact of the bloom on desalination plants was crucial in the UAE – the filters of the reverse osmosis (RO) plants were blocked by the bloom and created a situation leading to the closing down of four desalination plants at Kalba, Port of Fujairah, Kohr Fakkan and Ghalila for more than a week. Foam, odour and change of water colour affected the recreation industry in the UAE, and many beaches were closed during the bloom period.

Hoagland and Scatasta (2006) [8] estimated the economic impact of harmful algal bloom incidents in the US at about $82 million/year, with the majority of the impact being seen on public health and commercial fisheries sectors. There were no proper estimations made on the impact of *C. polykrikoides* in the UAE due to the lack of documentation on social impacts, cultural practices and values. Decreased recreational opportunities, shifts in livelihoods, unreported illnesses, reductions in property values, lost seafood sales due to unfounded consumer fears (the "halo effect") and lost revenue from some untapped fisheries are just a few examples of economic effects not accounted for in this estimate. On the other hand, economic loss in Iran due to *C. polykrikoides* bloom was calculated to be about $500 million.

Ballast water could be one of the likely reasons for the occurrence of present *C. polykrikoides*. Since the Arabian Gulf is one of the high ship traffic areas in the world, UAE coasts are vulnerable to the attack of invasive species (harmful algae) through ballast water. Annually, nearly 50,000 tankers operate in this region through the Strait of Hormuz, and it has been estimated that 30 million cubic meters of ballast water is discharged from these tankers yearly. Consequently, this area has been characterised as an extremely high-risk area. Based on the ship movement and ballast water inflow in the UAE, the ballast water ranks first as possible sources that could have introduced the species in the UAE. In addition, the water current and aquaculture and fisheries activities are some of the other probable sources for the introduction of various HAB species. Meanwhile, there was a report on *C. polykrikoides* bloom in Pakistan (Soina pers. Comm.) before this incident.

The topography and nutrient availability played a major role in HAB formation, expansion and fish deaths in the UAE coastal waters. In general, water renovation and flushing rates are key factors for the restoration of water quality. Fishing harbours situated in the Fujairah coastal waters comprised a low flushing rate and high nutrient concentration. Thus, the increase in man-made changes in the coastal zone was the primary reason for these episodes. The artificial changes in the coast such as breakwaters, semi-enclosed beaches, fishing harbours and large ports in the urban areas are favourable for HAB species. An increase in coastal sheltered areas (recreational purposes) and related activities, such as dredging and reclamation, also cause alteration of the environment and variations in coastal dynamics that favour HAB events.

Eutrophication is considered one of the most pressing environmental problems in the Arabian Gulf countries as the rapid development of the bordering countries have led to nutrient enrichment of the coastal waters. The increase of nutrient concentration and enrichment in the coastal waters was the prime factor for the extended bloom in UAE waters as well as what contributed to the 2001 episode in Kuwait Bay (Gilbert *et al*. 2002). Furthermore, the upwelling in offshore waters, current patterns and unexpected rainfalls were the additional reasons for the occurrence of prolonged blooms. Moreover, global warming could be one of the reasons for the sudden increase of blooms in the Arabian Gulf. Pyke *et al*. (2008) [24] reported that without considering climate change, understanding the algal bloom dynamics and ecosystem changes will be impractical.

Causes for the first outbreak of *C. polykrikoides* were assessed on the east coast of the UAE as well as in the Arabian Gulf. The data collected during the bloom and non-bloom periods and from bloom and non-bloom areas revealed that the *C. polykrikoides* were growing well, and extended over a long period in nutrient enriched areas (Table 1) with medium salinity (35–37 psu). Whereas, in high salinity (41.5–42.2 psu) with fewer nutrient areas (Table 1), the bloom lasted for a week, as in the case of Dubai. Furthermore, it was not recorded where in the Abu Dhabi waters the salinity was higher than the incident areas (Ras Al Khaimah, Umm Al Quwain, Fujairah and Dubai).

The east coast is subjected to heavy traffic of commercial vessels that are known to be an important vector in the translocation of the resting cysts of harmful algae, and the port has been acting as a basin for resting cysts. The reason for *C. polykrikoides* blooms initially occurring on the east coast seems to be through ballast water and the water quality (salinity and nutrients) of the area (Fujairah). The bloom was then transported to the other areas, such as Ras Al Khaima, Umm Al Quwain and Dubai, by the influence of water currents. The heavy rain recorded a few days prior (26 March 2009) to the second bloom incident (1 April 2009) in Dubai, made changes to the water quality (high nutrients, less salinity) and promoted the growth of *C. polykrikoides* transported to these areas after the first incident at Port Rashid. The reason that *C. polykrikoides* blooms did not enter the coastal area of Abu Dhabi was probably due to the current direction, high salinity (44–52 ppt), and lower nutrient concentration than the nearby bloom areas. Furthermore, the temperature did not show any remarkable role in the bloom initiation or spreading in UAE waters. The *C. polykrikoides* blooms were recorded throughout the year, not in one place but several different places in the UAE. Occurrences of the bloom throughout the year, in different temperatures proved that it was not the primary factor initiating or extending the bloom and that it can tolerate a wide range of temperatures. However, the actual factor that triggers or trigged the *C. polykrikoides* bloom in UAE waters remained unidentified.

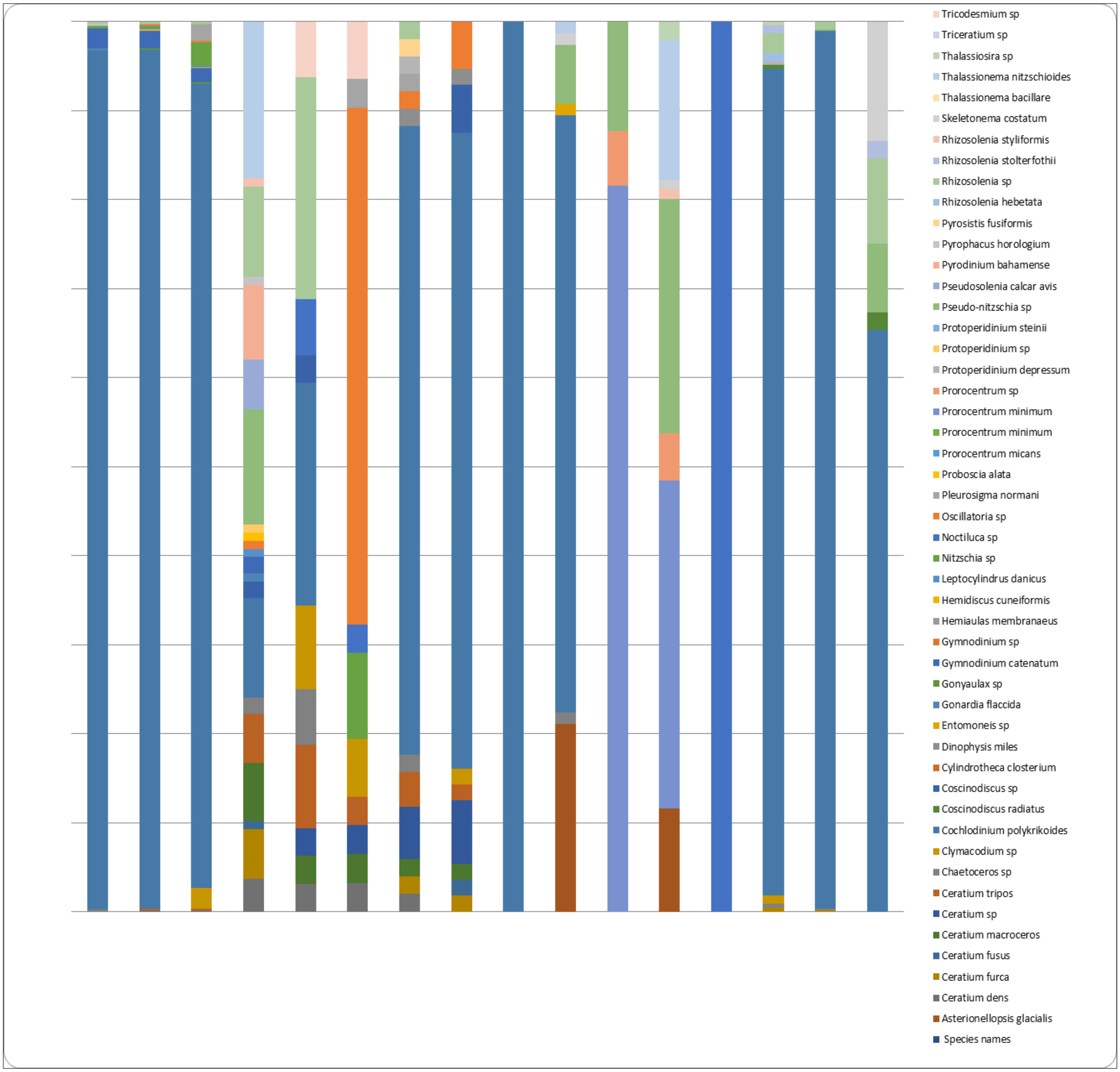

Fig 1: Percentage distribution of *Cochlodinium polykrikoids* and other phytoplankton species in different sampling sites.

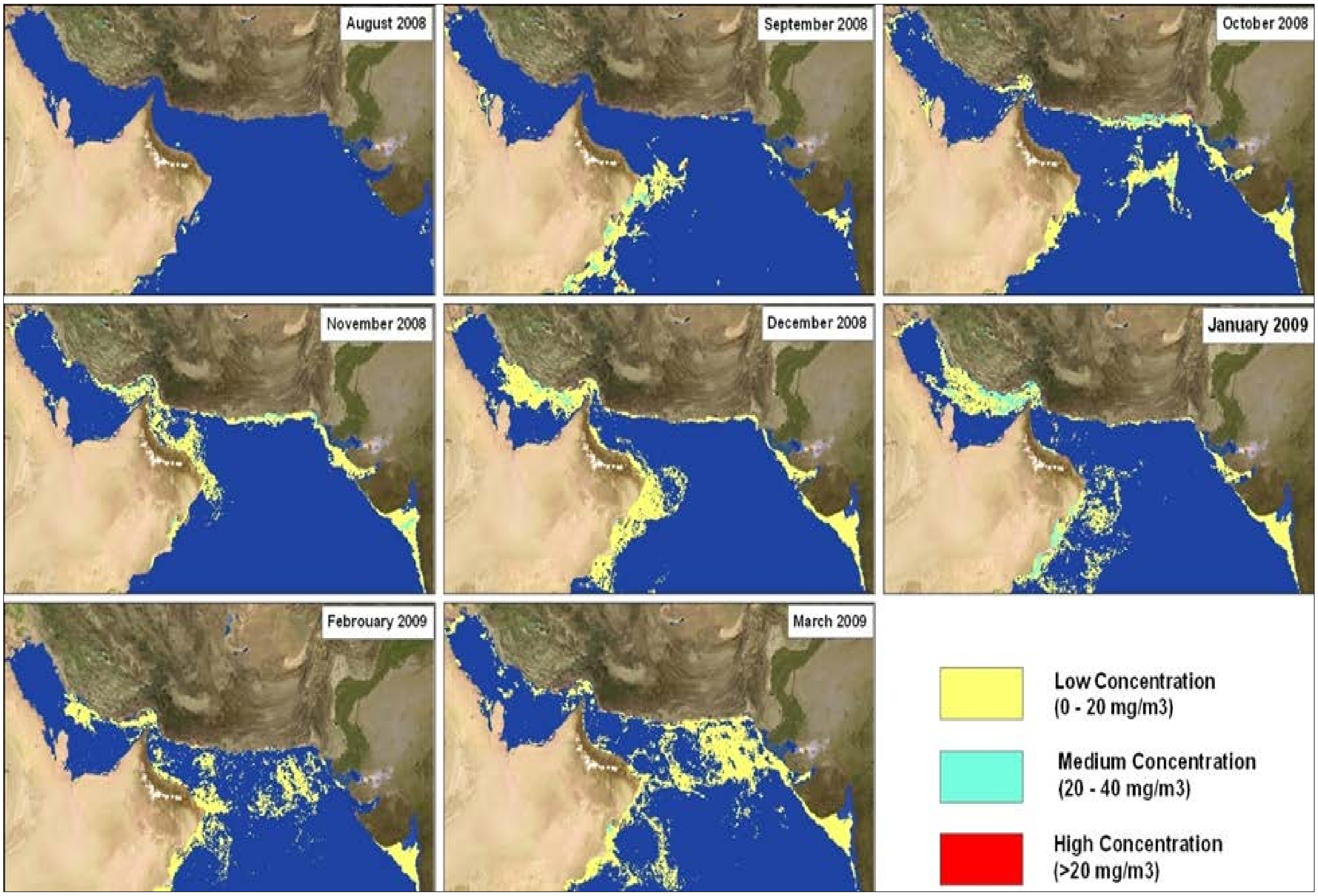

Fig 2: Chlorophyll Concentration during the *C. polykrikoides* bloom in UAE (August 2008 – March 2009)

Table 1: Water quality and Phytoplankton quantity during the bloom period in United Arab Emirates.

Bloom Incidences	Stations	Place Name	GPS Location	Tempe-rature (ºC)	Salinity (psu)	pH	D.Oxygen (mg/L)	Chlorophyll (µg/L)	Nitrite-N (µM/L)	Nitrate-N (µM/L)	Silicate-Si ((µM/L)	Phos-phate-P ((µM/L)	Total Numbers (cells/L)	*Cochlodinium polykri-koides* (cells/L)
Fujairah Incident-1 (28-10-2008)	Station-1	Dibba Accamia - fishing port inside	N:25º 36 416 E:56º 17 522	28.53	37.88	8.54	6.83	10.01	0.54	0.81	4.99	1.38	11000000	10606200
	Station-2	Dibba Accamia- fishing port outside	N:25º 36 327 E:56º 17 27	28.43	37.96	8.56	6.85	19.8	0.54	0.81	4.99	2.76	21000000	20349000
	Station-3	Dibba Al Hassan New Fishing port	N:25º 36 592 E:56º 16 508	28.41	37.33	8.53	5.34	12.6	0.54	0.81	4.73	2.46	16000000	15422400
	Station4	Open sea	N:25º 37 496 E:56º 17 219	28.01	37.18	8.01	5.1	0.28	0.27	0.34	1.77	0.94	120000	13320
Fujairah Incident-2 (17-11-2008)	Station-1	Dibba Accamia - fishing port inside	N:25º 36 416 E:56º 17 522	27.03	39.3	7.69	2.9	0.59	0.48	0.76	3.75	1.26	650000	535714
	Station-2	Dibba Accamia- fishing port outside	N:25º 36 327 E:56º 17 27	26.79	39.23	7.88	2.61	0.47	0.43	0.73	3.81	1.84	521428	385714
	Station-3	Dibba Al Hassan New Fishing port	N:25º 36 592 E:56º 16 508	27.54	39.35	7.69	0.14	0.12	0.43	0.65	3.68	1.79	99000	0

	Station-4	Dibba Al Hassan Old Fishing port	N:25º 35 113 E:56º 16 352	27.27	39.33	7.63	0.44	12.2	0.54	0.73	4.07	2.00	13500000	13500000
	Station-5	Asamak - Culture area	N:25º 36 522 E:56º 19 59	27.17	39.15	8.23	7.25	0.49	0.48	0.66	3.48	1.95	537500	531250
	Station-6	Al Fakeet	N:25º 36 133 E:56º 20 44	27.15	39.16	8.18	6.03	0.01	0.22	0.32	2.76	1.11	3000	2000
	Station-7	Fujairah Port-Desalination plant	N:25º 10 153 E:56º 21 545	27.68	39.07	8.32	9.13	5.1	0.46	0.68	3.55	1.63	5520000	5520000
Dubai - Incident-1 (11-1-09)	Station-1	Port Rashid Jetty	N.25º.16.52.2 E.055.17.19.2	21.9	42.4	8.1	9.68	52	0.48	0.71	2.56	2.00	133500000	133500000
Dubai Incident-1 (14-1-09)	Station-1	Port Rashid Jetty	N.25.16.52.2 E.055.17.19.2	21.17	42.1	7.9	5.3	0.8	0.43	0.48	2.50	1.90	180000	80000
	Station-2	Palm Deira	N.25º.17.11.6 E.055.18.47.7	20.92	41.5	8.17	9.22	51.4	0.54	0.73	3.42	2.21	56800000	0
	Station-3	Open Channel	N.25º.17.18.5 E.055.16.00.3	21.1	42	8.08	6.6	0.6	0.24	0.32	1.58	0.90	312000	8000
Dubai Incident-2 (02-04-09)	Station-1		N 25º 18.900' E 055º 15.709'	22.45	40.95	7.95	4.7	1.6	0.33	0.52	2.69	2.08	2000000	0
	Station-2		N 25ºº 20.469' E 055º 11.779'	22.61	40.93	8.08	5.92	33	0.39	0.61	3.15	2.00	11185000	10385000
	Station-3		N 25ºº 20.334' E 055º 11.193'	22.85	40.8	8.28	9	49.6	0.39	0.61	2.76	2.00	27811000	27411000
	Station -4		N 25ºº 09.707' E 055º 06.781'	23.6	40.85	8.03	5.03	0.2	0.22	0.32	4.73	1.03	52000	34000

Conclusion

Our study suggests that *C. polykrikoides* blooms are natural phenomena that might have increased due to anthropogenic activities. Ballast water, eutrophication and water currents are the probable reasons for the bloom initiation and expansion in the UAE. The artificial changes in the coasts and activities related to coastal development including dredging, landfilling, and infrastructure development caused variations in coastal dynamics that led the bloom to stay for a prolonged period, in a particular place. The movement of the blooms were mainly controlled by the water currents.

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