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First observations on phytoplankton and chlorophyll ecology in the coast of Hadhramout, Gulf of Aden

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Abstract
Data were collected from 5 sites at Hadhramout coast between October 2009 and January 2011 once a month; the characterization of these sites is based on phytoplankton biomass, enumeration and chlorophyll a measurements. The chlorophyll a pattern was found to have significant local and seasonal variations within the coast with a values ranging from 0.08 mg/m^3 in April at Mukalla area to 15.2 mg/m^3 in Sep. at BirAli area. Naturally this is a result of strongly changed phytoplankton mass level during the year. The seasonal dynamic character of phytoplankton characterized by summer raising that observed in May and July, with a clear excess in Broome and BirAli areas. Least phytoplankton content was observed in November in the Broome and Mukalla stations. 240 phytoplankton species were identified, in which Diatoms and Dinoflagellates were dominant taxonomic categories in abundance. Phytoplankton mass along the coast illustrates general decreasing from BirAli station in the west to Sharma in the east of Hadhramout coast.

Keywords: Phytoplankton; Chlorophyll; Hadhramout coast; Gulf of Aden; Upwelling; ecology.

1. Introduction
A marine coastal area is one of the most dynamic high-productivity areas of the ocean and an important component of life system, which harboring a wealth of species, genetic diversity, stored and revolves nutrients, also filtered contaminants and help to protect the beaches from erosion and storms. Although the water emergence upward (Upwelling) in coastal areas represent a small percentage of the global ocean surface, it contributes to a very large part of basic primary production and fish productivity of the ocean. Primary production of the waters of the coastal region is usually larger by 3 - 5 times of the open ocean, on the basis of units of the selected area, which is reflected particularly in the northwest regions of the Arabian Sea (Indian Ocean) [1, 2]. In this region the high productivity of pelagic planktonic communities provides food for large stocks of sardines and therefore tuna, which plays the primary role in the fisheries of the region and Yemen in particular. This region contains the Gulf of Aden and the coast of Hadhramout in particular, what gaining the latter important and effective role in the marine and coastal catches, reinforcing fisheries and income along most months of the year.

Comparing with extensive studies on the productivity of the components of this dynamic wealth that carried out in the open Arabian Sea during the past decades [3, 4, 5, 6, 7], the variations of the components of bio productivity in the coastal waters of the Gulf of Aden and the coast of Hadhramout in particular, are almost unknown. Furthermore the majority of current biomass of phytoplankton (estimated as chlorophyll a), and the productivity come from satellite observations [8, 9, 10].

The Gulf of Aden and its Hadhramout coast are located directly under the influence of the sub Somali sea current approaches, in summer in particular, which enters the Gulf mainly through corridors of Socotra Archipelago and rich in phytoplankton, the output of Upwelling phenomenon [11]. This coastal upwelling brings nutrients to the surface, where the light, creating a fuel to photosynthesis and phytoplankton growth, which in turn feed the zooplankton and fish.

The water column in Hadhramout coast is Characterized by good surface thermal mixing layers, which separated the under from the surface water by very stable layers (Thermocline) at a depth of about 100 meters; through the southwest summer monsoon this thermal deviations (Thermocline) rises to less than 25 meters deep and fixed in some areas [12, 13].

This coast is rich by primary productivity that expressed by about 600 mg carbon / m2 / day, and secondary (8 of 40 mg carbon / m 2 / day) and contributes by about 60% of the total annual fish landings of Yemen [14, 15, 16, 17]. It is also characterized by an abundance of sardines, tuna, Indian mackerel, which support the coastal pelagic fisheries of western Indian Ocean.

Phytoplankton of the northern part of Indian Ocean is very weakly investigated. In the same time great potential for the development of fisheries in these areas, make it necessary to clarify the laws of the spatial and temporal distribution of phytoplankton and the identification of regions of its massive development.

There is a paucity of knowledge about the spatial and temporal dynamics Oceanographic parameters in the northern coast of the Gulf of Aden, in particular the coast of Hadhramout. In addition there is no information on the phytoplankton diversity on the coast of Hadhramout. Thus, the main purpose of our study is to evaluate the spatial and temporal dynamics of phytoplankton biomass in relation to oceanographic parameters and the biological productivity represented by Chlorophyll in Hadhramout Coast (Gulf of Aden).

2. Materials and Methods

2.1 Studied area

Hadhramout coast (Fig. 1), complementary considered as part of the Gulf of Aden, occupies nearly one-third of the south Yemeni coast length with an estimated area of the continental shelf of about 70,000 km^2 (up to a depth 200 m). As estimated, the Hadhramout coast productive area (EEZ) of about 13500 km^2 (approximately 20%) [12, 14].

The coastal strip of the province of Hadhramout consists of a series of sandy beaches punctuated at intervals by configurations of rock protruding and mostly extends into the shallow water. The slope of sea bottom here abrupt, in terms of distance between the beach and the continental shelf, relatively narrow with an average of 15 kilometers, except in the northeast of the coast where it can be up to 60 km in width. The depth of the Gulf in the coast of Hadhramout as average about 1750 meters in the midst of the Gulf with higher depth up to 5370 meters [12, 14].

There are some sandy beaches with a backgrounds consisting of rocky heights, such as the shores of east Bir Ali, east Maifa Hajar, behinds Mukalla and Sharma.

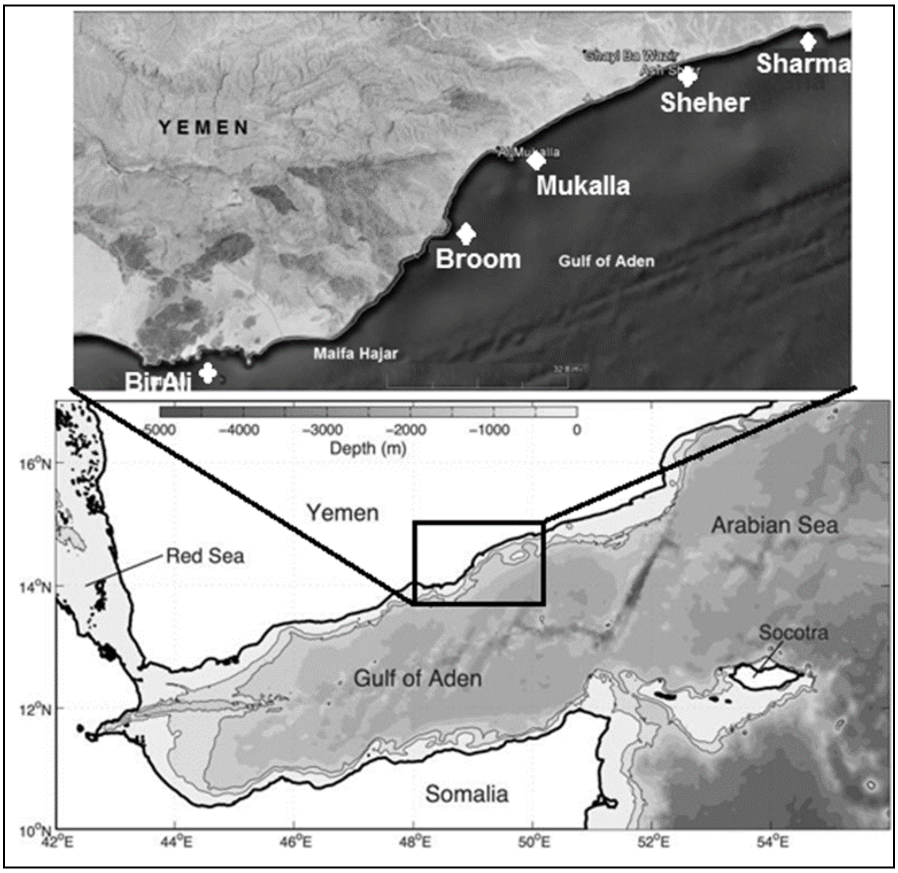

Fig 1: Showing the study area and sample sites in coast of Hadhramout, geographical locations are as follows: BirAli (N13 °55′, E48 °26′), Broom (N 14°22′, E49°00′), Mukalla (N14°48′, E50°00′), Sheher (N14 °43′, E49 °40′), Sharma (N14 °48′, E50 °00′)

This coastline consists of successive environments which is almost identical to a significant degree, such as sandy beaches, narrow coastal plains, rocky heights, sand dunes, proximity to the beach bottoms with a shallow rocky-sandy foundations and deep rocky bottoms. There are a lot of areas of environmental concern along the coast, from which the coast of Bir Ali and its islands and coral formations with elevated bioenergy; the coast of Broom distinguished by transition from a moderate high bioenergy for the Ras-El-Kalp coast to the high energy that extends along the east Broom area, Halla and behind of Mukalla areas. Hadhramout coast is also characterizes by wide sandy basses, which can prolongs the dry sandy beaches to a depth of over 100 meters; but it often limited between the tide curve and the depth of 30 meters.

Hadhramout coast is almost devoid of islands except what is common between the coasts of Shabwa and Hadhramout, a group of Bir Ali Islands which is considered the largest in the northern coast of the Gulf of Aden. Hadhramout coast Constitute nearly 14% of the Yemeni total coast and more than 20% of the North Gulf of Aden coast, which forms the southern border for 6 provinces of Yemen that enjoying notable fish reputation and served by more than 50 population locations which serving the activities of fishing and post-fishing industry; from the landing, grading, preparation and marketing, as well as exports. The coast is characterized by special location, which makes it between the effects of west Arabian Sea generally characterized by oligotrophic - a poor in the nutrients (nutrient-depleted) and plant life but oxygen-rich; and the middle of the Gulf of Aden characterized by being exposed to the phenomenon of Upwelling and eutrophic - a rich in bio nutrient and planktonic life [18]. Hadhramout coast is devoid of fresh water sources, if excluded a rare seasonal floods of Wadi Hadhramout and Wadi Hajar, which do not constitute a reason to coast salinity variability, due to the lack of quantities of water flows into the Gulf [19].

2.2 Sampling

Different indicators samples for this study were taken from the stations that have been selected along the Hadhramout coast, focusing on five main stations representing western border - east BirAli area (100-90m depth), and eastern - Sharma region (30m depth) and what between them representative of the cape of Broom (80-70m depth), Mukalla (50m depth) and Sheher (70m depth) (Fig. 1). Each station consists of five sub-stations located around the main station (rose system); the area around the central station is within distance 100 - 150 meters, in order to ensure the inclusion of the largest area of the region.

Emphasis has been placed on the analysis of monthly live plankton samples represents four time periods that we wanted to cover seasonal monsoons, summer and winter, and the interseasonal periods: the months Nov. 2009 represents the period between of summer and winter monsoons, January 2010 represented the winter monsoons and May 2010 represents a post-winter monsoon and prior to summer monsoon and August 2010 as representative of the summit of summer monsoons.

Phytoplankton sample took as part of a set of biochemical parameters which are will be a subject of forthcoming publications, and here discussed chlorophyll.

The analysis of phytoplankton were from all stations, the samples were taken from October 2009 till January 2011 once a month by plastic cylinder Niskin sized 5 liter specific to withdraw the samples from the required depths. In our case the samplers were dragged at a total depth about 90 meters (depends on the station depth). Phytoplankton samples were taken from the coast guard 10 meter solid fiberglass boat with outboard engine.

The sample was transferred to the 5-liter plastic containers cleaned with acid, and kept them refrigerated and shaded during transport to the laboratory. Samples were immediately filtered through 45 µm GF/F filters using polycarbonate in-line filters (Gelman) and a vacuum of less than 100 mm Hg. For the purpose of quantitative and qualitative analysis of phytoplankton, samples were directly fixed in Lugol's solution 1% and 3% formalin (formalin here equivalent to pH 8 with Borax - sodium tetraborate). Samples were preserved in a dark place until the analysis: through sedimentation process and siphon, each sample has been concentrated from the initial size of 250 ml to 10 ml, and then we took two 1 ml subsamples, each of which was spreaded on the microscopic plankton account cell (Sedgwick-rafter plankton counting chamber). It was screened and counted under magnification power 200-400 times accurately, considering all cellular squares. In some cases also we use the plankton calculate cell type (Petroff-Hausser counting chamber). To examine and diagnose taxonomic groups we used microscope of type Zeiss (Axioskop, 2plus, Germany). Although there is a relative abundance of micro phytoplankton (Nanophytoplankton) in samples, the emphasis was on groups larger than 20 microns, but it had been possible to calculate the approximate of some major categories of Nanophytoplankton. All the diagnostic and taxonomic considerations were took place using the considered guides, which followed for the Indian and the Pacific Oceans, in addition to many published scientific reports [20-25].

The laboratory analysis of samples was conducted with chlorophyll a upon method of fluorimetric guided by display of Arar and Collins [26], that the filtering of one liter of water sample through the membranous filter of acetate cellulose with openings 45 micrometers (45 µm Whatman GF/F), which is then put into a glass tube wrapped by aluminum (aluminum foil) and added to it 10 ml of concentration of 90% acetone for extracting. Then the sample in filter membrane is saved in the refrigerator (4 °C) through the night, grinding and centrifuge process to the mixture for five minutes at 5,000 r/min. the chlorophyll a checked and measured in the 13 mm glass tube using a direct method of concentration calibration, by High performance liquid chromatography (HPLC) apparatus, being guided by [27, 28].

3. Results and Discussion

Chlorophyll (a) concentration is cconsiders as an indicator of the mass of phytoplankton, which is the most common feature or characteristic of marine bio-productivity index. The chlorophyll (a) is an active and main pigment acts in photosynthesis process and common to all phytoplankton, so it is used as a measure or indicator of phytoplankton biomass. As a result of this study, Figure 2 shows the chlorophyll a quarterly cycle in different Hadhramout coast stations, and highlights the striking similarity of these cycles in terms of the clear number of peaks, timing and quantity, that representative here by tow concurrency typical peaks since each of which occurs after the beginning or the early summer and winter monsoons. The minimum was during the periods between monsoons, in spring and autumn, with distinction of large summer peak from the peak of relatively small winter blooming. Also it notes that these seasonal cycles, which were the outcome of the monthly tests for chlorophyll, also gives, to a large extent, good qualitative image for areas with high productivity: a Bir Ali, Broome area, namely western side of the coast with staying of the distinguishing seasonal productivity of the rest stations: Behind Mukalla, Sheher and Sharma.

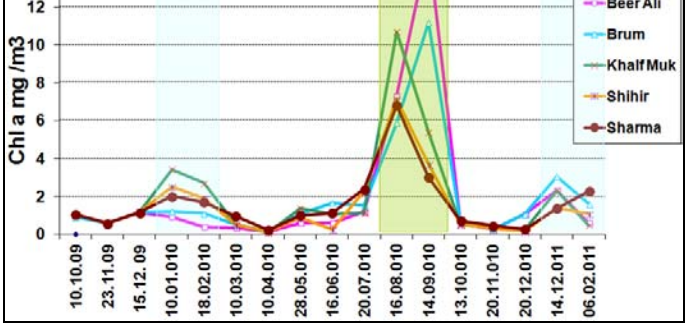

Fig 2: Chlorophyll a quarterly cycle in different Hadhramout coast stations (NEM - North-east Monsoon, SWM - South-west Monsoon)

The minimum value of the chlorophyll (a) concentration (an

average of 0.08±0.07 mg/m3) in the surface layer (10 meters) of each areas of the Hadhramout coast for a period of study, was observed in the period before the southwestern monsoon (April) in Mukalla station; and the higher (15.2±0.3 mg/m3) in the southwestern monsoon (August and September) (Figures 2 and 3).
Significant variations was not noticed between stations, except the relatively high-index (15.2 mg / m^3 in the Bir Ali station in September) in terms of distinguishing a frequency of gradual reduction eastwards only in this month (table 2). There are relative peak for this index were observed in January that reflects a winter bloom during the northeastern monsoon (Fig. 2).

Table 2: The variation in the values of chlorophyll (a) (mg / m3) in the surface layer of the Hadhramout coast

Month	Bir Ali	Broom	Mukalla	Shihir	Sharma
Oct 009	1.05	0.9	1.05	1.05	1.05
Nov	0.57	0.6	0.57	0.57	0.57
Dec	1.14	1.14	1.14	1.14	1.14
Jan 010	0.9	1.2	3.4	2.5	2
Feb	0.38	1.1	2.7	1.9	1.7
Mar	0.35	0.51	0.5	0.48	0.95
Apr	0.12	0.17	0.08	0.13	0.23
May	0.6	1.06	1.38	0.85	1
Jun	0.6	1.66	1.06	0.25	1.13
Jul	1.18	1.53	1.13	2.27	2.38
Aug	7.3	5.9	10.7	7.1	6.8
Sept	15.2	11.2	5.4	3.7	3
Oct	0.6	0.68	0.5	0.55	0.7
Nov	0.25	0.25	0.35	0.3	0.45
Dec	1.06	1.06	0.26	0.15	0.26
Jan 011	2.3	3.05	2.3	1.4	1.36
Feb	0.6	1.6	0.47	1.06	2.26

The Intermonsoon differences are distinct, from winter monsoon towards summer monsoon. High average concentration of green pigment - more than 4 mg / m^3 prevails during the summer monsoon with higher concentration, more than 6 mg / m^3 was recorded in all stations. Monthly spatial differences are clear, and in general the pigment indicator clearly differs in summer monsoon from the other internal seasons (Fig. 3).
Laboratory analysis showed that the extent of the fluctuation of enumeration of phytoplankton representative mainly by diatoms was pronounced - from 153 000 cells / m^3 in Mukalla area during the winter monsoon, to 16.247 million cells / m^3 during the summer monsoon in Bir Ali station, and as an average for the whole coast - 2.381 million cells / m^3 through the surface hundred meters. In contrast, the phytoplankton mass ranging, as they are in the mentioned regions and seasons, between 225 and 6880 mg / m^3 (Table 2 and Figure 4).
It is normal that the high mass and census of phytoplankton observed during the period and places of a high content of nutrient elements and reflects the chlorophyll concentration in areas of its richness, but not necessarily reflects a lack of enumeration and the mass of zooplankton or low temperatures in areas exposed to Upwelling as we can see from the above results.

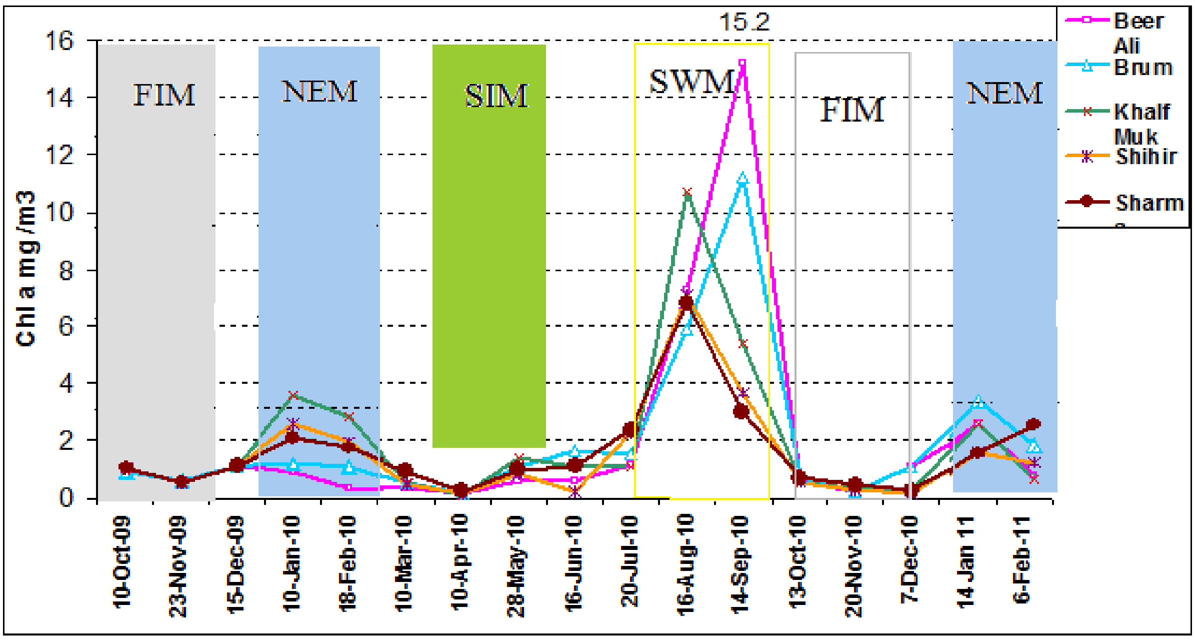

Fig 3: Spatial and temporal variability of chlorophyll a by seasons and stations of Hadhramout coast (**FIM** - Fall Inter-monsoon, **NEM** - North-east Monsoon, **SIM** - Spring Inter-monsoon, **SWM** - South-west Monsoon)

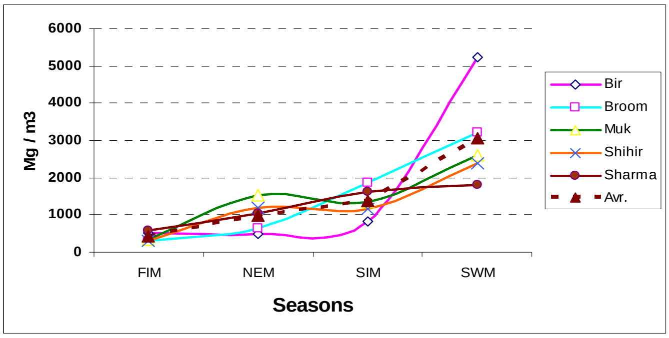

Fig 4: Illustrates the variation of phytoplankton mass among the seasons and stations of Hadhramout coast

The lack of variation in the content across studied coast areas (stations) indicate to symmetry and consistency of water masses in it despite the presence and absence of water eddies here and there. But the obvious differences observes only in the different seasons, which shows the extent of how the coast be affected and its biological productivity in these seasons, especially what notes by mass variation in the different stations during the south-west monsoon- August, (Fig. 4).

Phytoplankton mass level during the year strongly changed, and a population rate changed by regions more than 6 times. The seasonal dynamic character of phytoplankton characterized by summer raising that observed in May and July, with a clear excess in Broome and Bir Ali. Least phytoplankton content observed in November in the Broome and Mukalla stations (Table 3).

Although the number index of phytoplankton cells in our results was not so big, but the high concentration of chlorophyll and phytoplankton mass (mg / m^3) indicates that nana and picoplankton, who are not account their numerical and qualitative abundance due to unavailability of suitable devices, it can be as much as significant in Hadhramout coast that because what is known about the extent of their contribution to primary productivity, especially in the Arabian Sea, that sometimes reaches to a 75-80% [29, 6, 30]. This case necessarily play a large role in securing natural food to a crustaceans and fish larvae in the coast and thereby guarantee additional organisms and large biological productivity to the Gulf.

As noted earlier in this study, phytoplankton productivity in the coast expressed as chlorophyll was distinctly high, particularly during of southwestern monsoon months - July and August. This productivity is also high if expressed by mass indices and numerical abundance for plankton cells directly as shown in Table (3), which also illustrates the presence of two peaks of phytoplankton abundance in most areas of Hadhramout coast during January - February and August - September (Fig. 4).

Phytoplankton communities usually include several taxonomic groups and contribute to primary productivity and overlap between trophic levels; this is what varies with the seasons, what is due to a variation in the presence of nutrients, light and temperature. A seasonal pattern includes the changes in the composition and diversity of phytoplankton quality and its biovolume, the most important is the extent of the primary production, but the process of photosynthesis responds to specific factors that can be regulated by the change of qualitative composition and diversity or environmental divergence [31, 32].

As a result of this study the taxonomic analysis of phytoplankton highlights the biological components that contributed to the variations of chlorophyll a, where the diatoms was dominate the living communities on the coast zones. We have counted 240 species of micro phytoplankton, the numbers of its cells were calculated and the weight measured; Most of them have been diagnosed to species level. Diatoms and Dinoflagellates were dominant taxonomic categories in abundance (53% and 27% of the total density of phyto respectively); in terms of species numbers they have been 130 and 63 nomenclature respectively. The Coccolithophorids of three species, the other groups (blue-green and green algae) counted only 5 and 4 species, respectively. Many of these diagnosed species have been observed with high repetition, especially in some stations, table (Table 4).

It was possible to diagnosis a large numbers of phytoplankton categories that were counted from the summer monsoon and the period between monsoons. Most of what we have achieved to distinguish are the taxonomic of Diatoms and Dinoflagellates, which could be deliver the classification of most of them to species level. It was possible to nominate about 154 species during the summer monsoon compared to about 184 species category during the Intermonsoon. Phytoplankton mass along the section of the stations illustrates general decreasing from Bir Ali station in the west to Sharma in the east of the Hadhramout coast (Tables 3, 4).

Among Diatoms, the genus (Thalassiosira) was prevalent during the year with the highest concentration in the winter ($100x10^3$/L in January in Broome station). Rhizosolenia and Coscinodiscus relatively large size were found by low densities with relatively higher peak in the transition period between the summer and autumn (August - November). The Prevalence of the species of the genus (Nitzschia) was variably in abundance with a range up to more than 3000 cells / liter with typical fluctuating rate. As for chains forming genus (Chaetoceros), its prevalence is not homogeneous (unstable), whereat flourishing up to 4,000 cells / liter in March, followed by a period of two to three months where the abundance drops to below the noticeable.

In the summer months and under the influence of upwelling the presence of Diatoms represented by increasing percentages by more than 70% in phytoplankton, especially the species: *Climacodium* spp., *Thalassionema* spp. and *Rhizosolenia* spp..

The nature of the qualitative covariance of the Hadhramout coast from the northeast of the Arabian Sea (India's west coast) was diverging. The numbers and density of cyanobacteria are distinct - till 69% of phytoplankton community during the northeastern monsoon [33], while the Diatoms largely decreased so that its remains lacking in these areas sediments [34].

Besides the fact that this picture gives us a relatively good conception of the most productive areas of the coast, it is considered here a contribution to the clarification of the temporal rotation between regions, because the planktonic bloom on the coast has somewhat different timings.

The results of our study about variability of chlorophyll a concentrations in Hadhramout coast are reflected in satellite-observations for the whole Gulf of Aden and northwest of the Indian Ocean (NASA Sea WiFs satellite) (http: // www.nodc.noaa.gov). The dynamics of the green pigment concentrations photos in Hadhramout coast showing the extent of the impact of the monsoons changing and Somali current eddies and their coincide on the abundance and movement of green pigment in the Gulf in general, and the coast of Hadhramout the far north of the Gulf (Figure 5). Such figures are showing, as expression of monthly monitoring, the concentration and spreading behavior of green pigment in whole surface layer of the Gulf of Aden. Although these pictures shows that the natural state is the low concentration of pigment, except some pockets or columns, but the direct relatively high recordings usually reflect the fertility of the coastal areas comparing with the open sea [35, 36, 37].

Apart from the effect of currents and seasonal hydrology of the Gulf of Aden, the apparent biological characteristic to the coast of Hadhramout was a moderate heterogeneity (mesoscale variability), where monsoons cyclones and anticyclones dispersed eddies which usually prevail during southwestern monsoon. It controls the movement of the rich subsurface layers, and therefore the vertical migration of nutrients and their horizontal distribution [38, 39].

Table 3: the seasonal variation and abundance of phytoplankton in the coast of Hadhramout

Period	Bir Ali		Broom		Mukalla		Sheher		Sharma		The overall rate	
	Cell/ m^3	Mg/ m^3	Cell/ m^3	Mg/ m^3	Cell/ m^3	Mg/ m^3	Cell/ m^3	Mg/ m^3	Cell/ m^3	Mg/m^3	Cell/ m^3	Mg/ m^3
Nov. 2009 IM*	1625500 (853950-2215450)	520 (228-743)	950000 (818500-1214500)	314 (197-395)	1046000 (695850-1356500)	350 (185-440)	937000 (624500-1075000)	316 (168-380)	1725000 (956842-2035500)	586 (224-710)	1160000 (624500-2215450)	426.6±14.6 (314-586)
Jan. 2010 NE*	1423800 (474000-1600000)	500 (265-687)	1384900 (650000-1695000)	630 (275-840)	1525000 (153000-1915000)	1520 (225-1875)	1040000 (186000-3500000)	1200 (295-1730)	685800 (226000-1310000)	1050 (445-1874)	1211900 (153000-3500000)	980.5±23.5 (225-1875)
May *2010* IM*	1458000 (696500-1789600)	840 (540-1095)	6600000 (2500800-10580000)	1860 (1060-3625)	6265000 (2583400-11286000)	1360 (1012-2406)	3502500 (985856-5250000)	1150 (633-1565)	4500000 (2186000-5862500)	1630 (782-2150)	4435820 (696500-11286000)	1368.3±47.5 (540-3625)
Aug. *2010* SW*	12250000 (7100000-16247000)	5240 (2040-6880)	9853000 (3855600-12890000)	3220 (1488-4750)	6834500 (5100000-8530000)	2600 (1914-3430)	6100000 (2050000-8140000)	2380 (1458-3386)	4684300 (1700000-6570000)	1800 (512-2415)	7640300 (1700000-16247000)	3048±62.8 (512-6880)

*IM – Intermonsoon period
*NE – North East Monsoon
*SW – South west Monson

Table 4: Groups of micro phytoplankton in Hadhramout coast according to stations: (Abundant +++ (More than 800 cells / liter), ++ Frequent (800-300) and + Present (less than 100 cells / liter))

Groups, number of species	Bir Ali	Broom	Mukalla	Sheher	Sharma
Diotoms: 128	+++	++	++	+	+
Dinoflagellates: 63	++	+++	+++	+	+
Chlorophyceae:green algae 4	+	++	+	+	+
Coccolithophores: 3	+	+	++	+	+
Cyanophyta: Blue-green algae 5	++	++	++	+	+

Despite the absence of studies on chlorophyll of Gulf of Aden, but the numerous studies for western Indian Ocean and the Arabian Sea suggests, that the planktonic flourishing variability were represented by the index of chlorophyll a in the Hadhramout coast. It reflects what is going on and the nature of the quarterly sessions of chlorophyll of surface layer in the Indian Ocean in terms of timing and, peaks and the effect of the southwestern and north-eastern monsoons on the prosperity of phytoplankton; that affected by mineral richness (nutrients) resulting from Upwelling phenomenon during the summer monsoon and during the layer mixing of winter monsoon (figure 4, 5) [32, 40, 41, 42].

Not only the coast is recovering with mentioned prosperity, but these values can be extended to several hundred kilometers to the open ocean - into the Arabian Sea, by the influence of advection of water overturned eastward within the mainstream of Somalia and the forces of the local winds [31, 43]. Furthermore, the strong seasonal pattern of bioproductivity driven by the monsoonal dynamic distinctly appears in the northwest of Arabian Sea through the wide prosperity of phytoplankton and develops during two monsoonal periods [32, 44, 18].

We have found an obvious compatibility between the nature of the productivity of Hadhramout coast phytoplankton, and the results of the Gulf of Aden and the Indian Ocean studies which indicate an increase in quantity abundance of some parts of this ocean that exposed to the phenomenon of Upwelling. Quantity abundance are usually higher during the southwest monsoon by more than twice than through the north-eastern monsoon with distinction the richness of the Arabian Sea as compared with other parts of the Indian ocean, in particular the Gulfs of Bengal and Kaj [45, 46, 47, 36, 41, 48]. This is almost similar to what was mentioned by Marra *et al*. [49] and Savich [14] that the phytoplankton mass concentration and the value of the primary production for the north of Arabian Sea are relatively high during both Monsoons.

Generally speaking our results are found a good confirmation and correspondence in many scientific papers characterizing the north of the Indian Ocean and the Arabian Sea in recent years [50, 18, 51, 52].

It must be noted that our results were not in agreement with the findings claimed by some researchers [53, 54] who considered the Gulf of Aden as an oligotrophic area with very low nutrient concentrations. This contradiction may be because the nature of the chosen study sites, be coastal or offshore regions, or because of incompetence of the analysis of satellite altimetry data at that time.

In addition to that demonstrated by results of this study distinct richness of the coast of Hadhramout, that well known by its multiple species with its multispecies fisheries. Hadhramout coast also features its richness in primary productivity of 685 mg C / m 2 / day, and secondary productivity, ranging between 14-68 mg C / m 2 / day [55, 6], and contribute a share of the enormous quantities of fish landed in the whole Yemen - between 24% and 30%) (For the years 2006 to 2010). This coast is characterized by an abundance of Indian fatty sardines (*Sardinella longiceps*, Indian mackerel *Rastrelliger kanagurta*) and tuna (yellowfin tuna *Thunnus albacares*) that support the coastal surface and pelagic catch of the Gulf of Aden by more than 30 thousand tons of fish annually [56, 57].

The important outcome in this aspect of the study is the clarity of phytoplankton abundance and effect of Upwelling and a horizontal influx on gradation of synchronization repetition of the planktonic bloom for whatever reason, be due to equipped by nutrients rising from the bottom which confirmed here partially, or through the abundance of dissolved organic matter due to the high dynamic activities herein or even continuous plankton abundance in this coast (table 3, figure 3 and 4). This last question remains open to study and comparison of special address the uncertainty in understanding of the planktonic blooming in the Gulf of Aden as a whole and particularly the coast of Hadhramout.

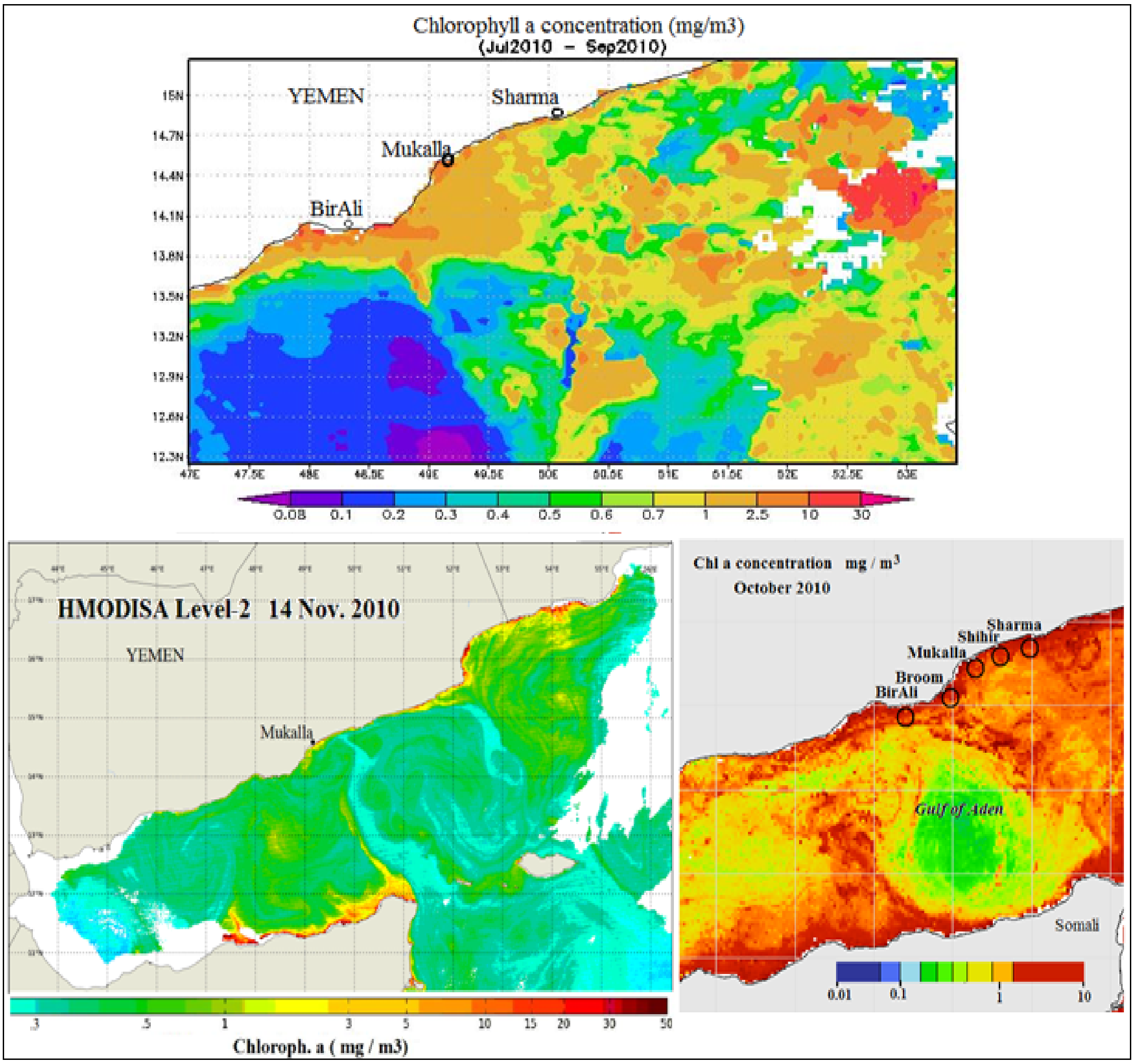

Fig 5: SeaWiFs images show high and low chlorophyll (a) concentration in Gulf of Aden (Reference: http: // www. Afro-sea. Org. Za/mrsu/flags.php)

Species of phytoplankton in Hadhramout coast in according to stations: (Abundant +++ (More than 800 cells / liter), ++ Frequent (800-300) and + Present (less than 100))

Group, the number of species	Bir Ali	Broom	Mukalla	Sheher	Sharma
Diotoms (Bacillariophyta) 128	+++	++	++	+	+
Actinocyclus spp.	++	++	+++	+	+
Asteromphalus flabellatus	+++	++	++	+	+
Amphora spectabilis	++	++	++	+	+
Amphora ovalis	+	+	+	+	+
Ampphora hyaline 295/l	+	+	+	+	+
Amphora crassa	+	+	+	+	+
Amphora ventricosa	+	+	+	+	+
Amphiprora alata	++	++	+	++	++
Bacillaria paradoxa	++	++	+	++	++
Bacteriastrum delicatulum	++	++	+++	+	+
Bacteriastrum hylinum	++	++	++	+	+
Bacterastrum deliculatum	+++	+++	+++	+	+
Bacteriastrum mediterranean	++	++	++	+	+
Biddulphia rhombus	++	++	++	+	+
Brachysira vitrea	+++	++	+++	+	++
Cocconeis sp.	+	+	+	+	+
Cymbella norvegica	+	+	++	++	+
Cyclotella stylorum	+++	+++	+	+	+++
Cyclotella striata	+++	+++	+	+	++
Cosinodiscus nitidus 247/l	++	+	++	+	+

Chaetocems denticidatum	+	+	+	+	+
Chaetocems didymus	+	+	+	+	+
Chaetocems pendulum	+	+	+	+	+
Chaetoceros socialis 380/l	++	++	++	+	+++
Chaetoceros gracilis 130/l	+	+	+	+	+
Chaetoceros affinis 320/l	+	++	++	+	+
Chaetoceros crinitus	++	+	++	++	+
Chaetoceros difficilis	-	-	-	+	+
Chaetoceros distans	-	-	-	+	++
Chaetoceros tortissimus	-	-	+	+	++
Chaetoceros subtilis	+	+	+	+	+
Chaetoceros lorenzianus	+++	+++	+	+	++
Chaetoceros danicus 188/l	+	++	+	+	+++
Chaetoceros curvisetus 100/l	+	+	+	+	+
Chaetoceros spp. 270cell/ L	+	+	+	++	++
Climacodium biconcavum	++	++	+++	+	+
Climacodium frauenfeldianum	++	+	+	+	+
Corethron criophilum	+	+	+	+	+
Coscinodiscus radiate 180/l	++	+++	+++	+	+
Coscinodiscus granii	++	+	++	++	+
Coscinodiscus curvatulus	++	+++	+	+	++
Coscinodiscus concinnus	+	+	+	+	+
Coscinodiscus radiatus	++	+++	++	+	+
Coscinodiscus superbus	+	+	+	+	+
Coscinodiscus marginatus 296	+	++	++	++	+++
Denticula elegans	+++	+++	+	+	++
Hemidiscus cuneiformis	+++	++	+	+	+
Planktoniella sol	+	+	+	+	+
Ethmodiscus sp.	+	+	+	+	+
Epithemia argus	+++	+++	++	++	++
Fragilaria striatula	++	+	+++	+	+
Fragilaria pinnata	++	++	++	++	++
Fragilaria oceanica	++	++	++	++	++
Guinardia striata	+	+	+	+	+
Eucampia zoodiacus	+	+	+	+	+
Hemiaulus membranaceus	+	+	+	+	+
Hemiaulus sinensis	+	+	+	+	+
Detonula pumila	++	+	+	+	+++
Grammatophora sp.	++	+++	++	+	+
Licmophora ehrenbergii	+++	+++	+	++	++
Melosira moniliformis	++	++	++	++	++
Melosira melosira 370/l	+	+	+	+	+
Melosira sulcata	+	+	+	+	+
Navicula longissima 180/l	++	++	++	++	++
Navicula distans	+++	+++	+++	+	+
Navicula gracilis	+++	+++	++	+	+
Navicula naviculaus	+	+	+++	+	+
Navicula peregina	+	+	+	+	+
Navicula rectangulata	++	+++	+++	+	+
Navicula punctata	++	++	+++	+	+
Navicula transitans					
Navicula splendida 32/l	++	++	+++	+	+
Nitzschia bicapitata	+	+	+	+	+
Nitzschia braantdii	+	+	+	+	+
Nitzschia sicula	++	++	++	++	+
Nitzschia angusta	+	+	+	+	+
Nitzschia fossilis	+	+	+	+	+
Nitzschia marina	++	+++	+++	+++	++
Nitzschia pelagica	+	++	+++	+++	+++
Nitzschia closterium 528/l	+++	+++	++	+	+
Nitzschia pungens	+	+	+	+	+
Nitzschia seriata 620/l	+	+++	+++	++	++
Nitzschia delicatissima	+	+	+	+	+
Nitzschia ventricosa	+	+	+	+	++
Nitzschia sigma	+	+	+	+	+
N. spp. 330/l	+	++	+	+	+
Pleurosigma capense	+	+	+	+	+
Pleurosigma directum	+	+	+	+	+

Pleurosigma directum	+	+	+	++	++
Pleurosigma angulatum 72/l	+	+	+	++	++
Rhizosolenia alata indica 128/l	+	+	++	+	+++
Rhizosolenia shrubsolei	+	+	+	+	+
Rhizosolenia styliformis	++	+++	+++	++	++
Rhizosolenia imbricata	+	+	++	+	++
Rhizosolenia bergonii 208/l	+	+	++	+	+
Rhizosolenia fragilissima	+	+	+	+	+
Rhizosolenia polydactyla	++	++	+	+	+
Rhizosolenia robusta	++	+++	++	+	+
Rhizosolenia setigera	+++	+++	+++	++	+++
Rhizosolenia stolterfothii	+	+	++	+	+
Schroederella delicatula	++	++	+++	+	+
Cocconeis scutellum	+	+	+	+	+
Shroderella spp. 662/l	+	+	++	+	+
Skeletonema tropicum	+	+	+	+	+
Skeletonema sp. 720/l	++	++	+++	++	++
Streptotheca thamensis	+	+	+	+	+
Streptotheca tamesis	+	+	+	+	+
Striatella delicatula	+	+	+	+	+
Surirella ovate	+	+	+	+	+
Surirella cruciata	++	++	+++	+	++
Thalassionema oestrupii	+++	+++	++	+	+
Thalassionema nitzschioides	+++	+++	+++	++	+++
Thalassiosira lineata	+++	++	++	+	+
Thalassiosira leptopus	++	+	+	+	+
Thalassiosira monile	++	+	+	+	+
Thalassiosira gracilis	+++	+++	++	+	+
Thalassiothrix frauenfeldii	+	+	-	-	-
Thalassiothrix longissima	-	-	-	+	++
Trichodesmium sp. 425/l	++	+++	++	+	++
Triceratium caudatum	+	+	++	+	+
Odontella sinensis	++	++	++	++	++
Unidentified ７1300/l	+	+	++	+	+
Dinoflagellates (Dinophyta): 63	++	+++	+++	+	++
Alexandrium catenella	++	++	+++	+	+
Dinophysis miles	-	+	+	-	++
Dinophysis acuta	++	++	++	+	+
Dinophysis acuminata	++	++	+++	++	+
Dinophysis spp.	+	+	+++	++	+++
Amphisolenia bidentata	+	+	+	+	+
Amphisolenia bifurcata	+	+	+	+	+
Amphidinium carteare 68/l	+	+	+	+	+
Amphidium sp. 4/l	-	-	+	-	+
Alexandrium catenella	+	+	++	++	+
Ceratium longipes	+++	+++	+++	+	++
Ceratium macroceros	+++	++	+++	+	+
Ceratium trichoceros	++	+++	+++	+	+
Ceratium controrum	+++	+++	+++	++	++
Ceratium carriense	+	+	+	+	+
Ceratium furca 15/l	+	-	+	-	+
Gymnodinium galeaeformis	-	-	-	+	+
Gymnodinium punctatum 30/l	-	+	+	-	++
Gymnodinium breve	++	++	++	+	+
Gymnodinium gracila	++	+++	+++	+	+
Gonyaulax polyedra	+++	+++	++	+	+++
Gonyaulax schilleri	+++	+++	++	+	+++
Gyrodinium spirale 140	+	+	++	+	+
Ceratium fusus	++	+++	+++	+	++
Ceratium macroceros	+	++	++	-	+
Noctiluca miliaris 60/l	+	+	++	+	++
Noctiluca scintillans	-	+	++	+	+++
Oxytoxum scolopax	-	-	-	+	+
Peridinium globules 100/l	+	++	++	+	+
Peridinium orientale	++	+	++	+	-
Peridinium africanoides	++	+	-	-	-
Peridinium nipponicum	++	++	+	-	-
Prorocentrum micans	+	++	++	+++	++

Proro. sigmoides	+	+	+	+	+
Proro. Graclie	-	-	-	+	+
Protoperidinium excentricum	+	+	+	++	++
Protoperidinium Divergens	+++	++	++	+	+
Protoperidinium Elegans	++	++	++	+	+
Protoperidinium quanerense	++	++	++	+	++
Protoperidinium roseum	-	-	-	+	+
Protoperidinium sp.	+	+	+	++	++
Porella perforate 40/l	-	-	+	+	+
Podolampas palmipes 35/l	+	+	+	+	+
Pyrodinium schilleri	+	+	+	++	++
Psedoceratium punctatum	++	++	++	+	+
Pyrocystis noctiluca	+	+	+	+	+
Pyrophacus horologium	+	+	+	+	+
Pyrocystis lunula	+	+	+	+	+
Unidentified ***12*** 20/l	+	+	+	+	+
Chlorophyceae.green algae 4	+	++	+	+	+
Akistrodesmus sp	+	-	-	-	+
Chaetomorpha indica	+	+	+	+	+
Chaetomorpha antennina	+	++	-	-	-
Chaetomorpha aerea	+	++	-	-	+
Coccolithophores (haptophytes): 3	+	+	++	+	+
Calciosolenia marrayi 180/l	+	+	++	+	
Cocolithus spp. 1300/l	+	+	+++	+	+
Gephyrocapsa oceanica 305/l	+	++	+	+	++
Cyanophyta: Blue-green algae 5	++	++	++	+	+
Oscillatoria thiebautii	-	-	++	+	+
Oscillatoria sp.	++	++	+++	+	+
Trichodesmium filaments 8/l	++	-	++	-	-
Trichodesmium erythraea	+++	++	-	-	-
Trichodesmium spp. Colonial forms	++	++	+	+	++

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