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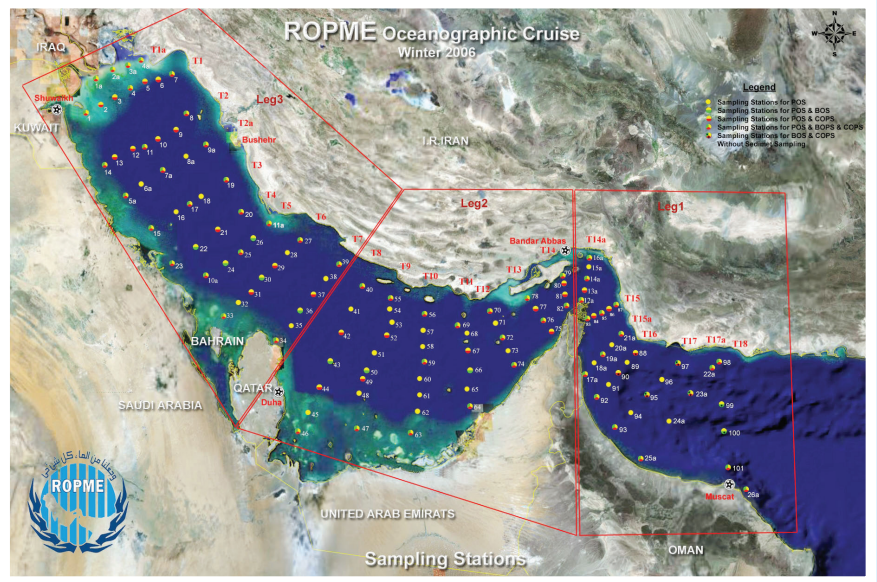

Technical Report Series

Technical Report : No. 12

Phytoplankton Cysts in the ROPME Sea Area

January 2020

Regional Organization for the Protection of the Marine Environment

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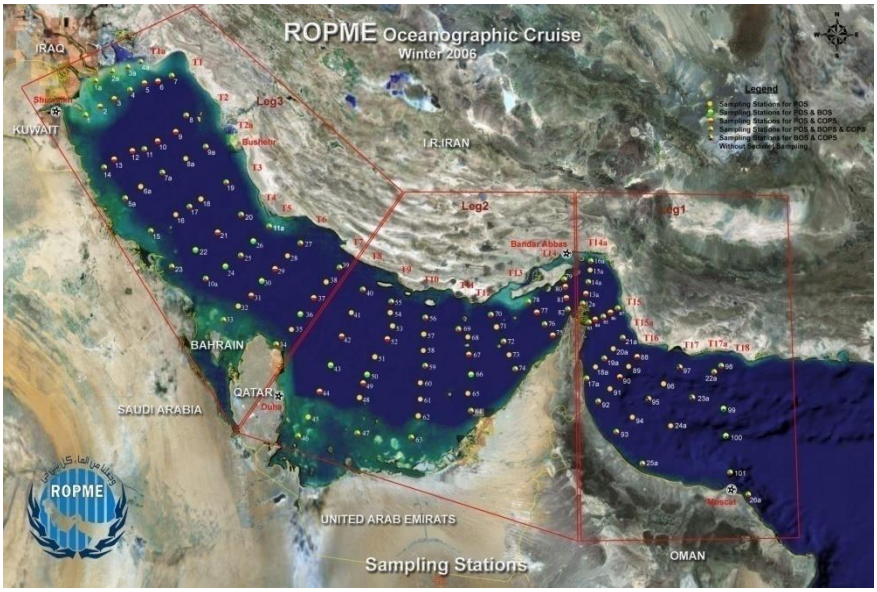
ROPME Oceanographic Cruise - Winter 2006



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ROPME Oceanographic Cruise - Winter 2006

Technical Report Series:

1. Physical Oceanography
2. Contaminants in Marine Sediments
3. Nutrients
4. Chlorophyll-*a*
5. Phytoplankton
6. Zooplankton
7. Decapod Larvae
8. Ichthyoplankton
9. Tintinnids
10. Meiobenthos
11. Macrobenthos
12. Phytoplankton Cysts

Disclaimer

This Report has been prepared by Dr. Gilan Attaran-Fariman from Department of Marine Science of Chabahar Maritime University (CMU), as the Principal Investigator on 'Phytoplankton cysts' under a contract with ROPME. The Report is being separately subjected to peer review and linking with other relevant data and information, in order to develop an integrated understanding of the ROPME Sea Area. Meanwhile, in order to bestow the benefit of viewing the results in their preliminary form and promote a general level of understanding of the marine environment of the Region, notwithstanding the possible delay by peer review, this document is being brought out as part of a special Technical Report Series in the very form in which it was submitted by the Principal Investigator. Owing to this reason, ROPME shall not accept responsibility on the accuracy of data or interpretations contained in this Report. ROPME does not also subscribe to any inappropriate terms used to denote parts or full of the ROPME Sea Area inadvertently used by the Principal Investigator or provided in the published references and citations.

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Preface

In recognition of the importance of the Oceanographic Cruises in the ROPME Sea Area to understand the state of the marine environment, ROPME Council has assigned high priority to the ROPME Scientific Cruises. In pursuance of the Council Decision CM12/7, ROPME was mandated to coordinate a comprehensive Oceanographic Cruise in Winter 2006. The Cruise was planned in such a way that the results and reports of the studies can find their way into the synthesis of ROPME State of the Marine Environment Report.

As a result of sustained efforts, cooperation of Member States, guidance of the designated Scientific Committee for the Cruise, encouragements from the Executive Committee of ROPME and the generous provisions made by the Council, the historic Winter Cruise was carried out successfully on board of M/V Ghods of I. R.Iran during 1st February and 11th March 2006.

Totally, 115 stations covering the RSA have been surveyed and 97 experts from ROPME Member States participated in the Cruise. The survey covered most of the main oceanographic disciplines.

The collected samples during the Cruise were distributed on a competitive basis to the competent laboratories in the Region and elsewhere for detailed analyses, while sub-sample sets were kept in ROPME Marine Sample Bank to enable repetitive analyses in future, when required.

To enhance benefits from the reproduced results of the Cruise among Regional scientific community towards a better understanding of the marine environment in the RSA and to enable furtherance of marine researches, ROPME Secretariat decided on the publication of the results in a series of Technical Reports as follows:

1. Physical Oceanography
2. Contaminants in Marine Sediments
3. Nutrients
4. Chlorophyll-a
5. Phytoplankton
6. Zooplankton
7. Decapod Larvae
8. Ichthyoplankton
9. Tintinnids
10. Meiobenthos
11. Macrobenthos
12. Phytoplankton Cysts

The present Technical Report is devoted to the spatial occurrence, diversity and abundance of phytoplankton cysts in the RSA. The analyses of phytoplankton cyst samples and reporting have been conducted by Dr. Gilan Attaran-Fariman, Associate Professor, Chabahar Maritime University (CMU), under a contract with ROPME.

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1. Introduction

ROPME Sea Area (RSA) is one of the most important subtropical water bodies in the world. This Region includes the Inner part of RSA, Strait of Hormuz and the Sea of Oman. In the last decade, phytoplankton researches in the world and RSA have been the center of attention due to the role of phytoplankton in ocean as primary production and in forming Harmful Algal Blooms (HABs). Most of the studies on the phytoplankton in the RSA are currently focusing on motile stage of species identification, abundance, composition, red tide, toxic species, and eutrophication, and recently cyst stages.

Many phytoplankton produce non-motile resting stage either in their life cycle or under unfavorable conditions such as temperature, salinity fluctuation, nutrient depletion and low light (Anderson *et al.*, 2003). The resting cysts deposit to the sediment as viable dormant cyst and can survive in the sediment for several years (Dale, 1983). After dormancy period and in favorable conditions, cysts germinate to motile stage and establish a new population (Figure 1). Phytoplankton cysts act in the sediment as "seed bank" and environmental indicators (Dale, 2001). This seed plays an important role at different harmful bloom phases; that is, switching from non-motile cysts to vegetative phase dividing population that initiates blooms. And encystment could be responsible for sudden bloom termination. The presence of the cysts in an area can represent species that have not been found previously in the plankton motile stage. Uncommon, short-lived plankton cells can be easily missed in plankton surveys, or some areas can be difficult to sample in particular seasonal conditions. Therefore, sediment sampling can be a useful addition to plankton surveys.

Most researches have focused on resting stages of Dinofalgellate and Raphidophytes because of the cyst role in HABs and only a few studies pertain to diatoms resting spore as microfossil (Dale, 1983; McQuoid and Hobson, 1996; Anderson *et al.*, 2003; Hallegraeff and Hara, 2003; Edvardsen and Imai, 2006). Almost 75% of HABs forming Species are dinoflagellate (Smayda 1997). Approximately 10% of the 2000 motile marine dinoflagellates are known to produce benthic resting cysts as part of their life history (Head, 1996; Bravo & Figueroa, 2014) including many harmful species that cause red tides and can survive under unfavorable conditions such as ballast tanks (lack of light) and are introduced to the new areas.

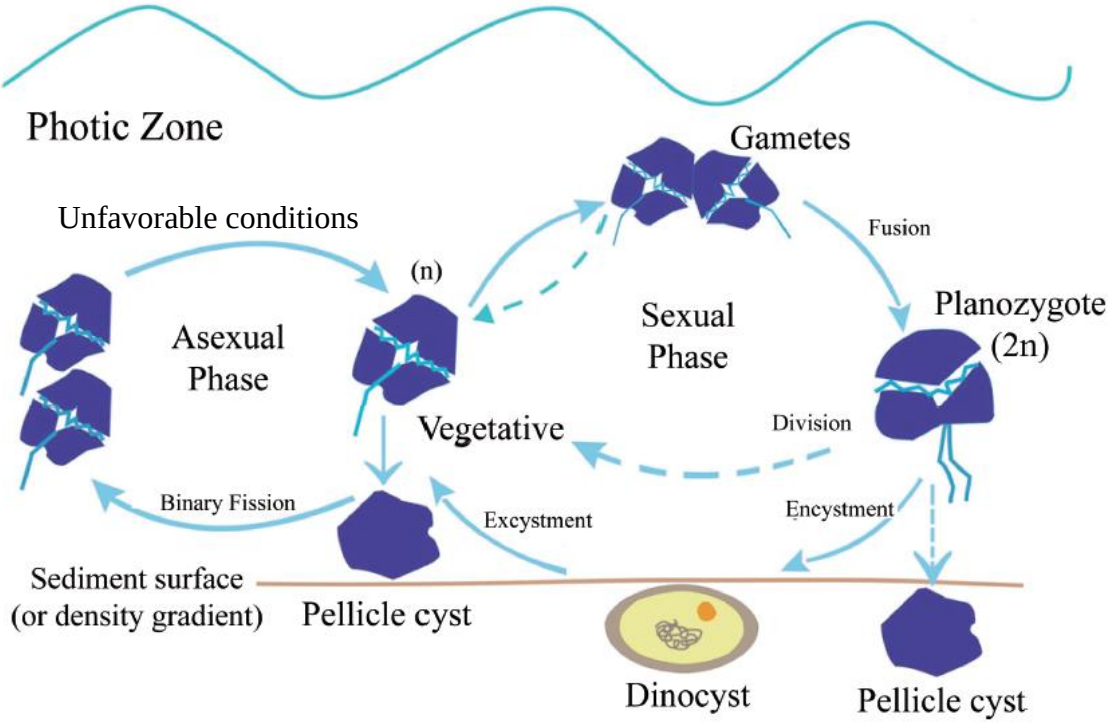

Figure 1: General life cycle of dinoflagellate cyst (after Walker et al.1984)

Although the importance of cyst studies have been quite well acknowledged in the literature, research on cyst assemblages of the RSA is fairly limited. There are some qualitative and quantitative surveys on dinoflagellate cysts from recent sediment in the Inner RSA, the Sea of Oman (Middle RSA) and Arabian Sea (Outer RSA). For example, some of these have been carried out by Bradford (1975), Bradford and Wall1 (1984), Zonneveld (1997, 1999, 2000, 2001), Attaran-Fariman (2007, 2016). Some plaentological studies have also been carried out in the Middle RSA as part of Netherlands Indian Ocean Programme (NIOP 1992-1993) by Wendler (2002), Marret and Zonneveld (2003). However, the majority of these works have focused on palaeontological study of the cysts. This method of the cysts processing can damage fragile HABs forming Species.

Chattonella and dinoflagellate cysts flora of some limited coastal area (9 sites) of the Iranian side of Middle RSA have been studied by Attaran-Fariman (2007). Some cysts species were identified in that research. *Chattonella* resting cyst has also been surveyed in the Middle RSA by Attaran-Fariman and Bolch, 2014. Cysts flora dispersion and identification of the Middle RSA (Iranian side) have been studied in 48 stations from depth of 2m to 28m by Attaran-Fariman (2016). This study provides identification of cyst stage of HABs forming Species and identifies key areas for potential presence of the HABs forming Species in the

future. Husain and Lewis (2004) surveyed dinoflagellate cysts in the sediment of Kuwait coastal area; however, this work is briefly reported in a conference abstract. There is no study on diatom resting spore in the RSA and all studies are on diatom resting cells.

There is no information on the identification of the cysts flora from other ROPME Cruises. Within the framework of "ROPME Oceanographic Cruise in Winter 2006", resting stage of phytoplankton species is investigated in the RSA. The present study aims to study cyst spatial distribution, abundance and diversity of phytoplankton cyst in collected sediments from different stations of the RSA.

2. Materials and Methods

2.1 Sampling Areas and Sediment Collection

Sediment samples were collected with Van Veen Grab from 27 stations of RSA in February and March 2006 during ROPME Winter Cruise. The surface sediment samples, from each station, were transferred to the little bottles and preserved in formaldehydes 4%. The stations were located in the three legs and 16 transects off the inner part of ROPME Sea Area, Strait of Hormuz and the Sea of Oman. Figure 2 shows position of sampling stations along RSA. Table 1 also demonstrates geographical positions, stations, sampling dates, times, IDs, depths, legs, transects, and observed sediment nature.

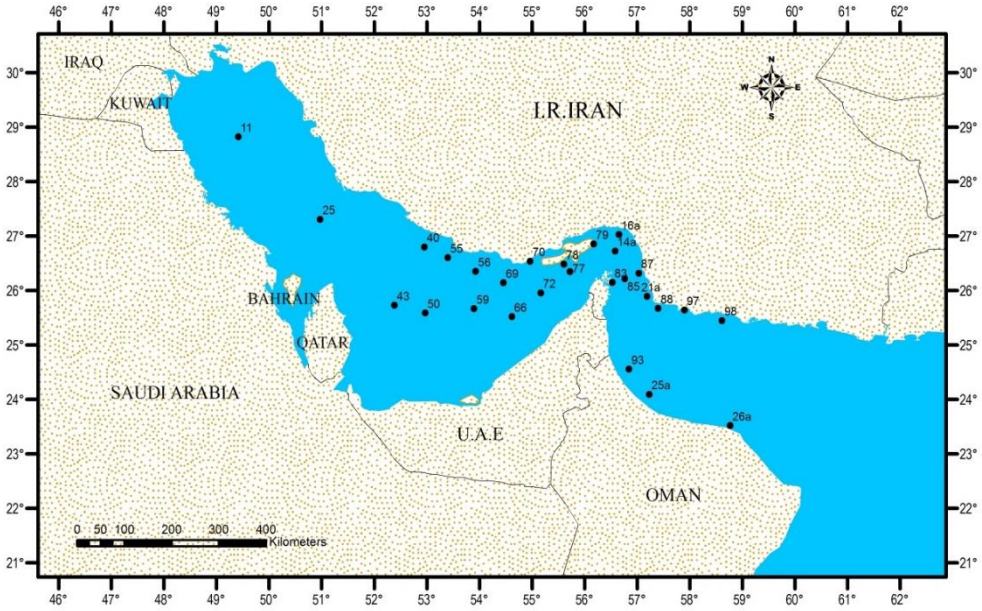

Figure 2: Map of sampling stations of phytoplankton cysts in the RSA, ROPME Oceanographic Cruise - Winter 2006

Table 1: Detail of sediment sampling stations for phytoplankton cyst study in the RSA

Sampling Date	Leg	Sampling Time	Transect	Station	Position		Depth (m)	Sample ID	Observed Sediment Nature
					Lat. (N)	Long. (E)			
2/2/2006	1	18:30	18	26a	23° 31.000′	058° 46.100′	53	T18S26a	Fine Sand
3/2/2006		23:45	18	98	25° 26.801′	058° 36.914′	50	T18S98	Muddy (Green Sediment)
4/2/2006		20:00	17a	25a	24° 05.505′	057° 13.813′	50	T17aS25a	Fine Sand & Silt
5/2/2006		1:00	17	93	24° 33.147′	056° 50.739′	67	T17S93	Fine Sand
5/2/2006		18:00	17	97	25° 38.200′	057° 54.000′	54	T17S97	Muddy
5/2/2006		22:15	16	88	25° 40.043′	057° 24.048′	65	T16S88	Muddy
7/2/2006		1:00	15a	21a	25° 53.400′	057° 11.300′	57	T15aS21a	Muddy
7/2/2006		11:55	15	87	26° 18.900′	057° 01.800′	26	T15S87	Muddy
8/2/2006		8:00	15	85	26° 13.000′	056° 46.000′	104	T15S85	Fine Sand / Silt
8/2/2006		11:30	15	83	26° 08.763′	056° 31.767′	95	T15S83	Coarse Sand
8/2/2006		21:00	14a	14a	26° 43.200′	26° 43.200′	64	T14aS14a	Muddy
9/2/2006		11:30	14a	16a	27° 01.400′	056° 39.300′	30	T14aS16a	Muddy

Table 1. Contd.

Sampling Date	Leg	Sampling Time	Transect	Station	Position		Depth (m)	Sample ID	Observed Sediment Nature
					Lat. (N)	Long. (E)			
13/2/2006		8:30	14	79	26° 51.046′	56° 10.378′	45	T14S79	Silty Sand
13/2/2006		19:40	13	77	26° 20.671′	55° 43.561′	61	T13S77	Muddy
14/2/2006		10:15	13	78	26° 28.769′	55° 36.474′	45	T13S78	Muddy
14/2/2006		14:15	12	70	26° 32.104′	54° 57.957′	44	T12S70	Muddy
14/2/2006		18:45	12	72	25° 57.254′	55° 10.080′	72	T12S72	Sandy
15/2/2006	2	16:30	11	66	25° 31.090′	54° 37.156′	42	T11S66	Silty Sand
15/2/2006		21:45	11	69	26° 08.382′	54° 27.506′	75	T11S69	Coarse Sand
21/2/2006		5:45	10	56	26° 20.905′	53° 55.864′	93	10S56	Sandy Mud
21/2/2006		12:45	10	59	25° 39.885′	53° 53.944′	43	T10S59	Muddy Sand
22/2/2006		7:10	9	50	25° 35.092′	052° 58.225′	39	T9S50	Sandy Mud
22/2/2006		16:00	9	55	26° 36.057′	053° 24.057′	86	T9S55	Muddy Sand
22/2/2006		20:30	8	40	26° 47.800′	052° 57.400′	86	T8S40	Sandy Mud
23/2/2006		13:15	8	43	25° 43.513′	52° 23.170′	33	T8S43	Clean Sandy
3/3/2006	3	6:15	5	25	27° 18.290′	050° 58.400′	67	T5S25	Mud
7/3/2006		9:50	2	11	28° 49.120′	049° 25.120′	44	T2S11	Sandy Clay

2.2. Sediment Processing

Sediment of each station was processed for cyst identification and enumeration, using biological standard sieving method (Wall and Dale, 1968; Matsuoka and Fukuyo, 2000). 1-2g of sediment, with six replicates from each station, mixed with Sea water and water slurry were sonicated for 1 minute to separate cysts from detritus particles. After sonication, the subsamples passed through 100µm and collected on the 20µm sieves. The residues on 20µm sieve were collected on a petri dish and panning process was accomplished. The supernatant water including cyst was transferred to a vial and the final volume was noted. The whole

volume of this preparation was counted on the sedgewick-rafter chamber using invert microscope (Nikon, TS100).

2.2.1. Qualitative Cyst Investigation

Qualitative analysis of the phytoplankton resting cyst is based on cyst morphology, which is different from motile stages and is even more complex. The species description is completed when all stages in the life cycle of each species are contrasted.

Morphological features that are considered to identify phytoplankton cyst of the RSA are cyst shape, size, color, wall structure and ornamentation, archeopyle types and other paratabulations, cyst contents and presence of mucilaginous layer.

Each taxon has been identified at species level, where possible. As some species produce very similar cysts, which without germination experiment their identification at species level is almost impossible; these remain at genus level or as unknown species in this study. All sediment samples, from RSA Cruise 2006, were kept in the formaldehyde for a long time preservation; therefore, cyst germination and formation of a uni-algal culture for unknown species were not possible. All cysts were identified based on published literature (e.g. Wall and Dale, 1968; Sonneman and Hill, 1997; Attaran-Fariman *et al.*, 2012; Mertens *et al.*, 2015) and description details for each cyst were documented in a separate Monograph.

The qualitative analysis was carried out based on 27 sediment samples collected by Van Veen Grab from RSA in Winter 2006. Individual cysts were separated by micropipette under microscope. After photography, they were transferred to the microtube containing 4% formaldehyde for long time preservation.

2.2.2. Microscopy

Individual cyst was photographed by a digital camera attached to the invert microscope (Nikon, TS100) and phase contrast light microscope (Olympus) at Chabahar Maritime University in Iran. Microscope lenses with magnifications of 10×, 20×, 40× and 100× have been used in combination with 10× magnifying oculars to achieve magnifications of 100×, 200×, 400× and 1000×. Cyst size is an important feature for identification of some phytoplankton cysts. All cysts were photographed and their sizes were measured using stage micrometer.

2.2.3. Cyst Nomenclatures

Some phytoplankton cysts have different systems of classification, especially in dinoflagellate cysts. Palaeontologists have developed a palaeontological classification based on cyst features and phycologists classified them based on motile cells features. Therefore, one species sometimes has more than one scientific name.

In the RSA, all taxonomical nomenclatures are based predominantly on biological names. In some species, if affinity of their motile stage has not been reported from water column (such as *Echinidinium* spp), their paleontological name was used. Based on morphological characteristics, some dinoflahellate taxa were grouped together. For example in some cysts of the genus *Gonyaulax*, the biological names are *Gonyaulax spinifera* complex. In this case, their palaeontological names are used in the analysis of RSA samples.

2.2.4. Quantitative Analysis

For quantitative analysis of the RSA phytoplankton cysts, 27 sediment samples with at least five replicates were observed. Totally 135 samples of 1-2g wet sediment were screened and all the cysts were identified and counted.

The concentrations of the cysts were calculated for each replicate as the number of cysts per gram of dry sediment (cysts g^{-1} dry sediment). Known weight of wet (1g) sediment was oven dried at 70ºC for 24 hours to estimate the proportion of the water in the wet sediment (Matsuoka and Fukuyo, 2000). Cyst abundance was calculated for five replicates in all 27 stations by using the following formula;

Cyst concentration $=N/W\ (1-R)$

In which:

N- Number of cysts,

W – Weight of sediment

R – Proportion of water in the sediment.

2.2.5. Data Statistical Analysis

Some parameters are provided by ROPME to compare with fluctuations of cysts' data. These parameters have been measured in the bottom layer, where sediment samples were collected for the cyst surveys from the RSA in Winter 2006. These parameters are as

follows; Levels of organics contaminants and metals in cysts samples surface sediments, nutrient salt and water quality in bottom water layers and the result of grain size analysis.

All statistical analyses were carried out by using MS Excel 2000, SPSS 24.0, CANOCO 4.5 (Ter Braak and Smilauer, 2012), PRIMER 5.0. All maps are provided by ArcGIS 10.1

Diversity indices that have been determined in the RSA samples are as following:

- Margalef's index (species richness), this refers to the number of species in a sample.

$$d = (S - 1) / \ln N$$

Where

S- The number of species,

N- The total number of individuals in the sample

- Shannon's index (species diversity), the species diversity is commonly expressed by the Shannon-Wiener diversity index H´

$$H = -\sum_{i=1}^{S} p_i \ln p_i$$

Pi is the proportion of individuals belonging to the *i*th species in the samples. Pielou's index (community evenness)

$$E = H' / H'max$$

Where,

the number of the Shannon diversity index

is the maximum value of H

The cyst abundance of the RSA was used to make a lower triangular similarity matrix using Bray-Curtis coefficient (Bray and Curtis, 1957). The similarity matrix was subjected to cluster analysis by group average method to assess the similarity and variations among stations. RIMER software (Version 5.1.1) was used for similarity analysis.

The multivariate analyses were used to find the relationship between dinocyst species (including HAB forming Species), concentration and environmental parameters, organic matter and metal level in the surface of the sediments where the cyst samples were collected.

Data were tested for normality first. If data were not normal, they would be transformed to $Log_{10,}$ and standardised for analysis. In order to find the relationship of top dominant taxa with environmental factor and the type of distribution (i.e. unimodal or linear, according to the length of the first gradient), Detrended Correspondence Analysis (DCA) has been used. If the gradient of species abundance was more than 4, then a direct method with the Canonical Correspondence Analysis (CCA) would be used (Ter Braak and Smilauer, 2012). The Forward selection was applied to find the parameters that have the greatest influence and make any changes in the data of dinoflagellate cysts species. Statistical significance for each axis was determined by Monte Carlo Test (Ter Break, 1986).

3. Results and Discussion

3.1. Phytoplankton Cyst Composition in the RSA

A total of 93 phytoplankton cysts types, belonging to 30 genera, have been identified in the RSA from 27 samples collected in Winter 2006. In phytoplankton cysts, dinoflagellate was the dominant group in terms of cyst density and occurrence in the sampling sites. Many phytoplankton groups produce resting stage during their life cycles including; dinoflagellate, diatoms, raphidophytes, green algae and cyanobacteria. Among these phytoplankton groups, most reports are on marine dinoflagellate resting cyst and diatom resting cell. Green algae and cyanobacteria resting stages are well studied in the freshwater (Elegaard *et al.* 2017).

Diatoms produce two types of resting stages; resting cell that is morphologically similar to vegetative cell and resting spore (hypnospore) that is morphologically not similar to the vegetative cell. Dinoflagellates also produce two types of cysts; resting cyst that is the result of sexual reproduction called “hypnozygote”and temporary cyst that is produced under unfavorable conditions. Few dinoflagellate resting cysts are morphologically similar to the motile cell; e.g: *Zygabikodinium lenticulatum,* the cyst is brown and motile stage has the same morphology with transparent color. Raphidophytes cysts are usually round and two genera in this group produce resting cyst; namely, *Chatonella* and *Heterosigma.*

In the RSA, among resting cyst producers of phytoplankton group, dinoflagellate, diatom, and raphidophytes were found. All classifications are based on Algaebase (Guiry and Guiry, 2017). Phytoplankton cyst that has been identified in the RSA, from Winter Cruise 2006 belong to the 3 phyla and 3 classes as following;

Empire: Eukaryota

Kingdom: chromista

Phylum: Miozoa

Class: Dinophyceae

Phylum: Bacillariophyta

Class; Coscinodiscophyceae

Phylum: Ochrophyta

Class: Raphidophyceae

The number of species in each phytoplankton class is summarized in Table 2. In the RSA sediment samples of Winter 2006, 99% of species belong to dinoflagellate resting cyst and only 0.64% belong to the diatoms resting stages and 0.39% to raphidophytes.

Table 2: Number of phytoplankton cysts in different phytoplankton classes in the RSA, Winter 2006

Phytoplankton Class	No. species
Dinophyceae	88
Coscinodiscophyceae	1
Unknown diatom	2
Raphidophyceae	2

The high diversity of the dinoflagellate in the RSA is not surprising; all previous studies indicate that this group is predominant in surface sediments and they are well-studied (Orlova and Morozova, 2009; Ellegaard and Ribeiro, 2017). In the RSA, the sediment samples were collected from surface sediments. In order to assess dinoflagellate cyst in the recent sediment, it seems that the sampling of surface sediments is sufficient to verify the dinoflagellate cyst (ie; Joyce *et al.*, 2005; Uzar *et al.* 2010; Aydin *et al.* 2015).

In the RSA surface sediments, diatom's abundance comprises 0.64% only (Table 3). There is a gap in the knowledge about diatom resting spore and its role in sediments. Most studies of diatoms resting spore are mainly related to palaentological and fossil records that

are reviewed in the earlier literature (Hargraves and Viquez, 1985; McQuid and Habson, 1996). In most studies that documented diatoms' resting spore survey in the coastal area, sediment samples have been taken by core from below the surface sediment (e.g. Anil *et al.*, 2007). In the marine sediments, viable resting stages of diatoms were reported from 30-40cm below the surface sediments (McQuoid *et al.*, 2002; Lundholm *et al.*, 2011; Ellegaard *et al.*, 2013).

72 species of diatoms resting stage have been reported from coastal area of RSA (Iranian side of the Sea of Oman and Strait of Hormuz) from 2-9m depth (Attaran-Fariman *et al.*, 2017). In this study, the top 20cm of surface sediment samples were taken from 2m to 9m depth, in which most of diatoms were in resting cell stage, morphologically similar to the motile cell. In Winter 2006 Cruise, the depth of sampling stations was between 30m and 104m, and the diversity of diatoms resting stages (including resting cell and resting spore) appears to be greater in shallow coastal areas.

Table 3: Abundance (%) of different phytoplankton cysts groups in the RSA, Winter 2006

Phytoplankton cyst	Abundance (%)
Diatom	0.64
Dinoflagellate	99.06
Raphidophyte	0.39

Cyst forming Species in the raphidophytes group belong to two genera; namely, *Chattonella* and *Heterosigma*. In the RSA, sediment samples comprise 0.39% of cyst flora. In the class of raphidophytes, resting cyst from natural sediments have been documented for 3 species in the *Chattonella* genus and one species in the *Heterosigma* genus (Attaran Fariman and Bolch, 2014; Kim et al., 2015;). The raphidophytes cysts are mostly found in the shallow coastal water (Orlova and Morozova, 2009).

There are some cysts in the RSA that their motile affinity is unknown from water column, or refer to them as group (for example *Gonyaulax spinifera* complex); therefore, their palaeontological names have been used. Table 4 shows the list of identified species of cysts in the RSA and their palaeontological names.

Table 4: List of identified phytoplankton cyst, biological name based on motile form and paleontological name in the RSA, Winter 2006

Biological Name	Paleontological Name
Dinoflagellate	
Order: Peridiniales	
Family: Protoperidiniaceae	
Protoperidinium americanum	Cyst of *Protoperidinium americanum*
Protoperidinium shanghaiense typeA	*Trinovantidinium applanatum*
Protoperidinium shanghaiense typeB	*Trinovantidinium applanatum*
Protoperidinium oblongum	*Votadinium calvum*
Protoperidinium claudicans	*Votadinium spinosum*
Protoperidinium leonis	*Quinquecuspis concretum*
Protoperidinium cf. leonis	*Quinquecuspis cf. concretum*
Protoperidinium denticulatum	*Brigantedinium irregular*
Protoperidinium humile	Cyst of *Protoperidinium humile*
Protoperidinium conicoides	*Brigantedinium simplex*
Protoperidinium conicum	*Selenopemphix quanta*
Protoperidinium latissimum	*Cyst of Protoperidinium latissimum*
Protoperidinium avellana	*Brigantedinium cariacoense*
Protoperidinium punctulatum	*Cyst of Protoperidinium punctulatum*
Protoperidinium divaricatum	*Xandarodinium xantham*
Protoperidinium subinerme	*Selenopemphix nephroides*
Protoperidinium thorianum	Cyst of *Protoperidinium thorianum*
Protoperidinium compressum	*Stelladinium stellatum*
Protoperidinium minutum	Cyst of *Protoperidinium minutum*
Protoperidinium sp1	*Brigantedinium spp*
Protoperidinium sp2	
Protoperidinium sp3	
Protoperidinium sp4	
Protoperidinium sp5	
Protoperidinium sp6	
Protoperidinium sp.7	
Niea torta	Cyst of *Niea torta*
Family: Congruentidiaceae	
Motile affinity is Unknown	*Echinidinium delicatum*
Motile affinity is Unknown	*Echinidinium bispiniformum*
Family: Amphidiniopsidaceae	
Motile affinity is Unknown	*Islandinium cf. minutum*
Archaeperidinium minutum	Cyst of *Archaeperidinium minutum*
Family: Kolkwitziellaceae	
Diplopsalis lenticula	Cyst of *Diplopsalis lenticula*
Diplopslis sp.1	*Durbridinium sp*
Diplopslis sp.2	*Durbridinium sp*
Diplopelta parva	Cyst of *Diplopelta parva*
Diplopelta symmetrica	Cyst of *Diplopelta symmetrica*
Family: Thoracosphaeraceae	
Pyrodinium bahamense	*Polysphaeridium zoharyi*

Biological Name	Paleontological Name
Alexandrium pseudogonyaulax	Cyst of *Alexandrium pseudogonyaulax*
Alexandrium affine	Cyst of *Alexandrium affine*
Alexandrium tamarense	Cyst of *Alexandrium tamarense*
Alexandrium minutum	Cyst of *Alexandrium minutum*
Alexandrium sp1	
Alexandrium sp2	
Scrippsiella trifida	Cyst of *Scrippsiella trifida*
Scrippsiella irregularis	Cyst of *Scrippsiella irregularis*
Scrippsiella trochoidea	Cyst of *Rhabdothorax erinaceus*
Scrippsiella precaria	Cyst of *Scrippsiella precaria*
Scrippsiella Cf. regalis	Cyst of *Rhabdothorax gerenus*
motile affinity is Unknown	*Calciperidinium asymmetricum*
Calciodinellum albatrosianum	Cyst of *Calciodinellum albatrosianum*
Calciodinellum operosum	Cyst of *Calciodinellum operosum*
motile affinity is Unknown	*Leonella granifera*
Pentapharsodinium tyrrhenicum	*Calcicarpinum bivalvum*
Pentapharsodinium cf. tyrrhenicum	*Calcicarpinum bivalvum*
Bicarinellum tricarinelloides	Cyst of *Bicarinellum tricarinelloides*
Order: Gonyaulacales	
Family: Gonyaulacaceae	
Motile affinity is Unknown	*Bitectatodinium spongium*
Gonyaulax spinifera Complex	*Nematosphaeropsis labyrinthus*
Gonyaulax membranacea	*Spiniferites membranaceus*
Gonyaulax spinifera Complex	*Spiniferites mirabilis*
Gonyaulax digitale	*Spiniferites bentori*
Gonyaulax cf. scrippsae	*Spiniferites bulloideus*
Gonyaulax spinifera complex	*Spiniferites ramosus*
Gonyaulax spinifera complex	*Gonyaulax baltica*
Gonyaulax spinifera complex	*Spiniferites* cf. *delicatus*
Gonyaulax spinifera complex	*Spiniferites hyperacanthus*
Gonyaulax ellegaardiae	*Spiniferites pachydermus*
Gonyaulax sp.1	*Spiniferites* sp.1
Gonyaulax sp.2	*Spiniferites* sp.2
Lingulodinium polyedra	*Lingulodinium machaerophorum*
Lingulodinium sp	
Family: Protoceratiaceae	
Protoceratium reticulatum	*Operculodinium centrocarpum*
Family: Pyrophacaceae	
Pyrophacus steinii	
Order: Gymnodiniales	
Family: Gymnodiniaceae	
Gymnodinium catenatum	Cyst of *Gymnodinium catenatum*
Gymnodinium nolleri	*Cyst of Gymnodinium nolleri*
Gymnodinium microreticulatum	Cyst of *Gymnodinium microreticulatum*
Gymnodinium trapeziforme	Cyst of *Gymnodinium trapeziforme*
Gymnodinium inusitatum	Cyst of *Gymnodinium inusitatum*
Gymnodinium sp	*Gymnodinium sp*

Biological Name	Paleontological Name
Cochlodinium polykrikoides	Cyst of *Cochlodinium polykrikoides*
Family: Polykrikaceae	
Polykrikos hartmannii	Cyst of *Polykrikos hartmannii*
Family: Warnowiaceae	
Warnowia rosea	Cyst of *Warnowia rosea*
Biecheleria cincta = Woloszynskia cincta	Cyst of *Biecheleria cincta*
Unknown	
Dinocyst type1	
Dinocyst type 2	
Inocyst type 3	
Dinocyst type4	
Dinocyst type5	
Dinocyst type6	
Diatom	
Paralia sp.1	
Diatom unknown typeA	
Diatom unknown type B	
Raphidophyds	
Chattonella sp(raphidophyceae)	Cyst of *Chattonella* sp
Hetrosigma cf. akashiow	Cyst of *Hetrosigma cf. akashiow*

3.2. Phytoplankton Cyst Concentration

The cyst concentration in the surface sediment of the RSA was varied in different stations (Figure 3A and B). Total phytoplankton cysts per gram of dry sediment ranged from 2.26 cyst g^{-1} dry weight sediment (dws) in station 50 located in the Inner RSA to a maximum of 204 cyst g^{-1}dws in station 88 in the depth of 64 (Figure 3). Station 55 located in the Inner RSA with 127.75 cyst g^{-1}dws also had high phytoplankton cyst concentration (Figure 3). An average of 38.4 cyst g^{-1}dws was recorded in the RSA during Winter 2006. Average cyst concentration in stations located in the Sea of Oman, Strait of Hormuz and Inner RSA are documented in the Figure 3A. There were 10 stations located in the Sea of Oman, two stations in the Strait of Hormuz and 15 stations in the Inner RSA. Among these three areas the highest phytoplankton cyst concentration with an average of 52.33 cyst g^{-1}dws was observed in the Strait of Hormuz (Figure 4). The average cyst concentration in the sediment of Sea of Oman was higher than those of in Inner RSA.

Most of the cysts distributed in low concentration in the RSA, and some of the cysts found in extremely low concentration. This is comparable with those of other tropical regions (Dale and Dale 1992; Zonneveld 1997; Matsouka *et al.*, 1999; Godhe *et al.* 2000, 2001;

Srivilai *et al.*, 2012). The cyst concentration in some temperate regions is high (Lee and Matsuka, 1996; Kim 1999;). Cyst assemblage in the RSA in Winter 2006 was more variable than those in the other areas.

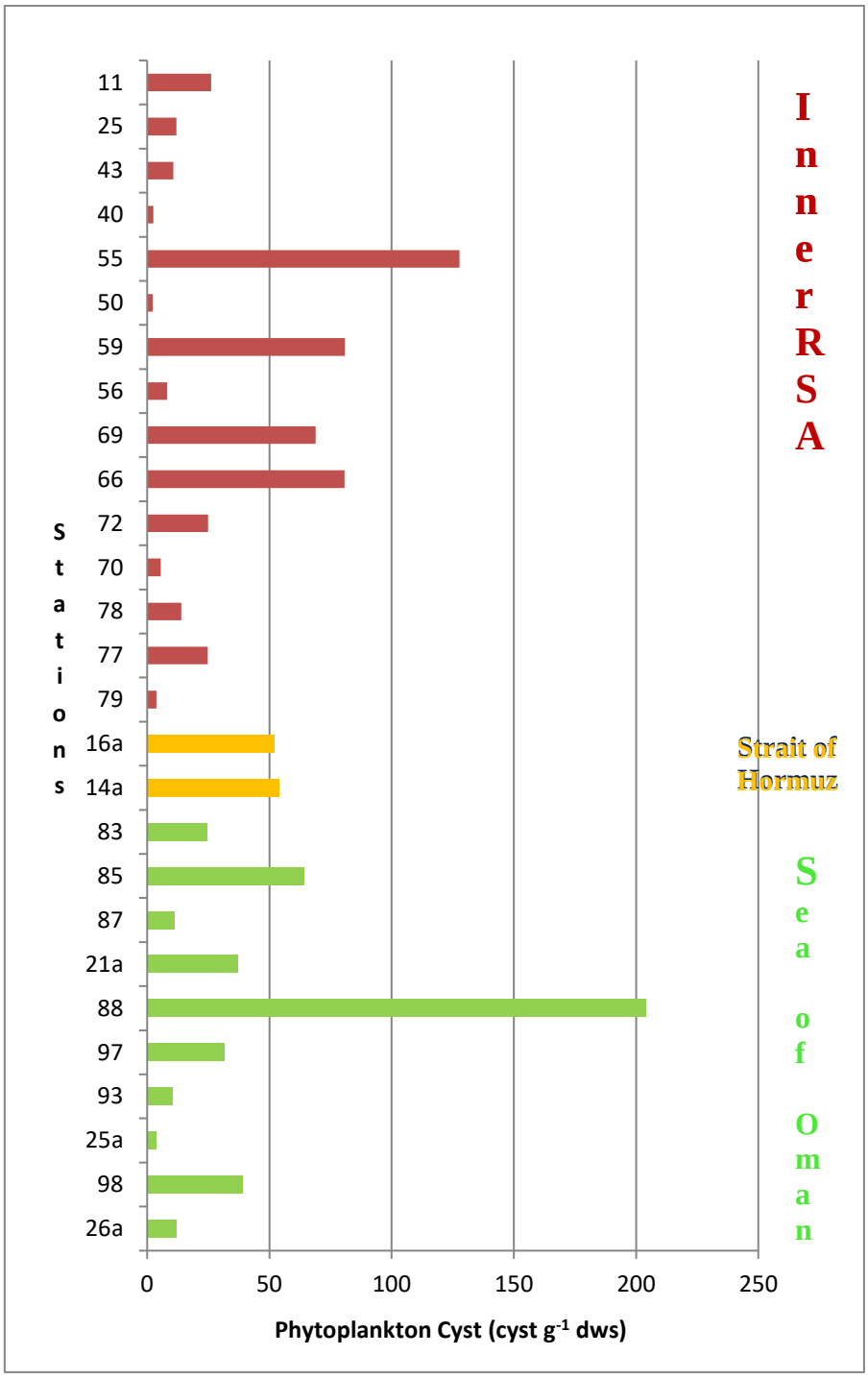

Figure 3A: Phytoplankton cyst density (cyst g^{-1}dws) of RSA in different stations, Winter 2006. Green color; Sea of Oman stations, Orange color Strait of Hormuz stations, Red color stations in the Inner part of the RSA

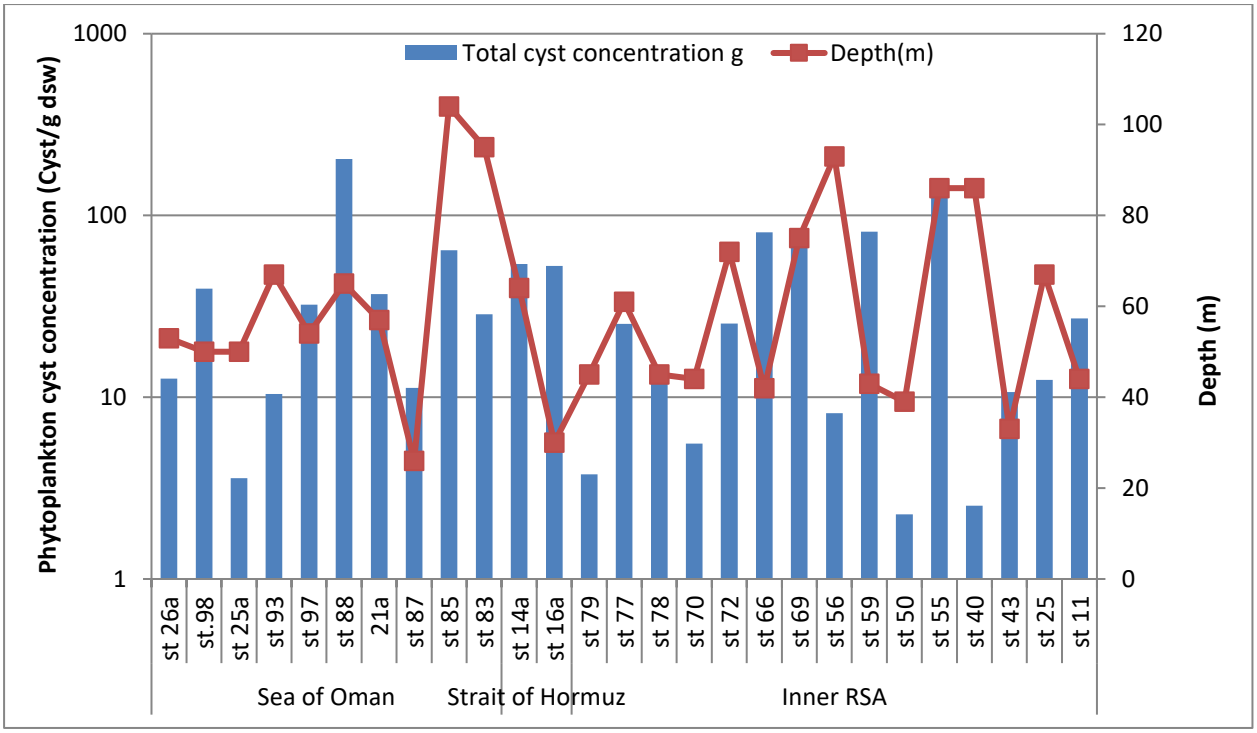

Figure 3B: Comparison of cyst density in the different stations with different depth in three regions of the RSA, Winter 2006

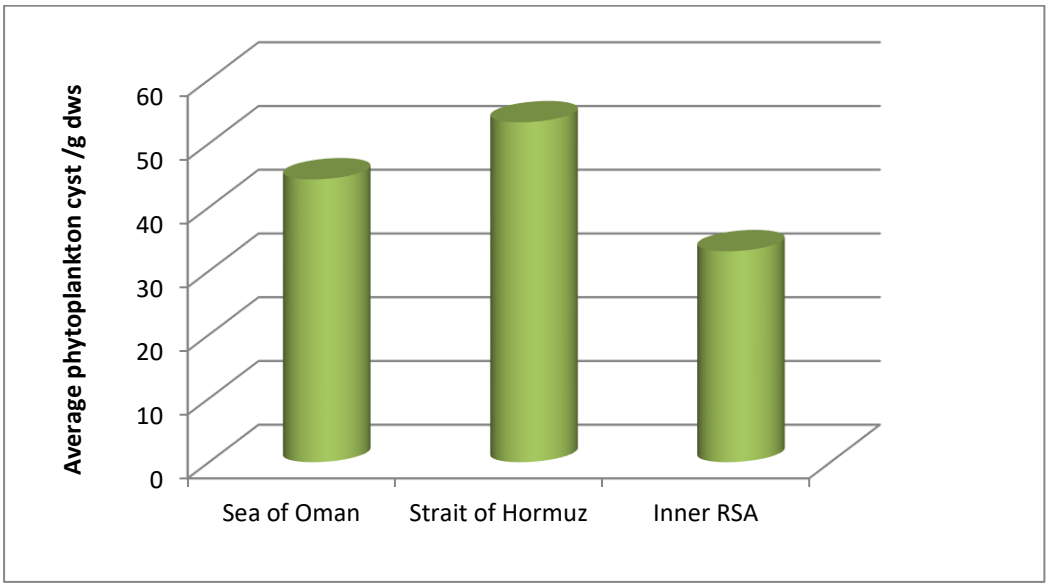

Figure 4: Comparison of average phytoplankton cyst concentration in different areas along ROPME Sea Area, Winter 2006

3.3. Dinophyceae Cyst

A Total of 88 dinoflagellate cysts (dinocysts) types representing three orders were recorded at 27 stations along RSA in Winter 2006. The present study revealed that dinocyst

was widespread along investigated stations of this research. About 10–16% of living 2294 species of dinoflagellate produce resting cyst (Gómez, 2012; Ellegaards *et al.*, 2017). Almost 45% of the total described dinocysts are presented in the RSA from depth of 30-104m in one sampling season. This suggests that the number of dinocysts might be more, if sampling covers all seasons. Attaran-Fariman (2016) found 80 dinocysts morphotype along Iranian coastal area of the Sea of Oman and Strait of Hormuz from depth of 2m to 28m in four seasons' samplings.

3.3.1 Dinocyst Abundance and Spatial Distribution in the RSA

In the dinophyceae class, the cysts species belong to three orders. The most abundant of the dinoflagellate order was Peridiniales, followed by Gonyaulacals and Gymnodiniales and unknown species comprising only 1% of the cyst abundance (Figure 5). This result is comparable with those of most studies that report the dominance of Peridiniales followed by Gonyaulacals cyst species in the marine sediments (eg. Morquecho and Lechuga-Devéze, 2003; D'Silva *et al.*, 2011; Mohamed and Al- Shehri, 2011).

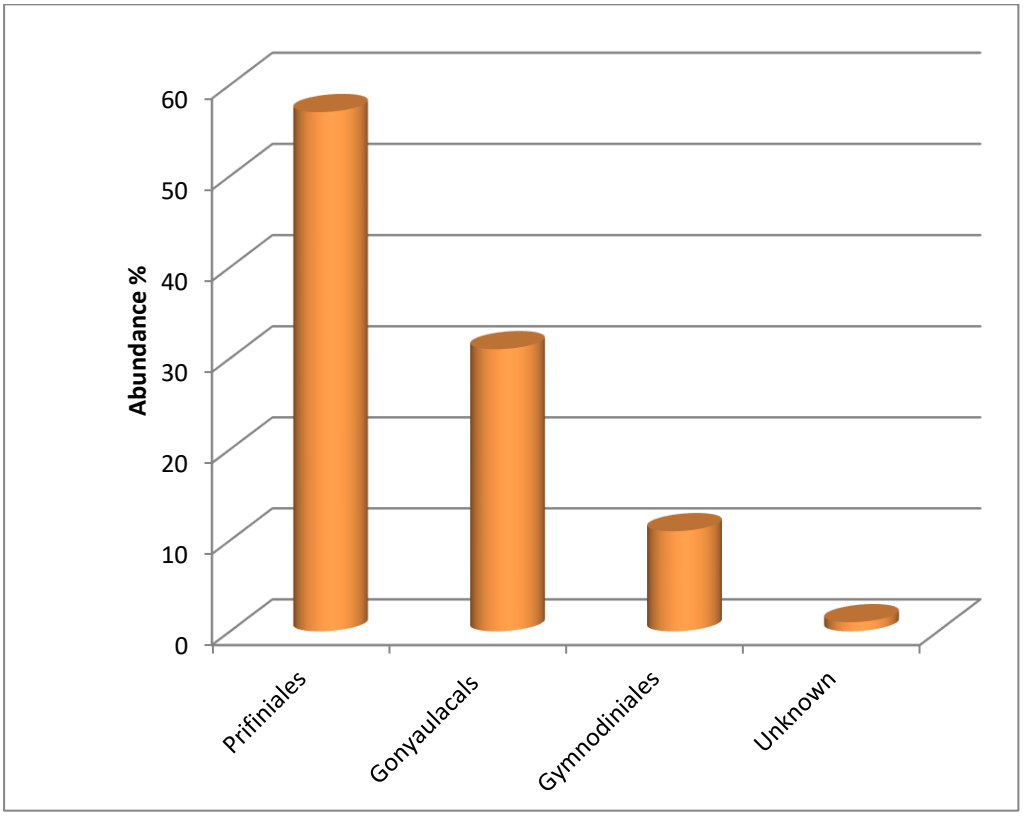

Figure 5: Abundance (%) of dinoflagellate orders in the RSA, Winter 2006

Cyst composition showed some important differences in different stations. Peridiniales cysts were recorded in every samples and composition of the cyst abundance varied from 22.7% to 100%. The highest order relative abundance were recorded in station 25a located along Oman in the Sea of Oman and in station 40 along Iran in the Inner RSA. The lowest relative abundance was recorded in the Strait of Hormuz along Iranian side (Figures 6 and 7).

The relative abundance of Gonyaulacals varied from 0% in stations 25a and 40 to 62% in station 50 along U.A.E (Figures 6 and 8). Highest relative abundances of Gymnodiniales were noted in the Strait of Hormuz along Iranian coast (45%) in station 87 (Figures 6 and 9).

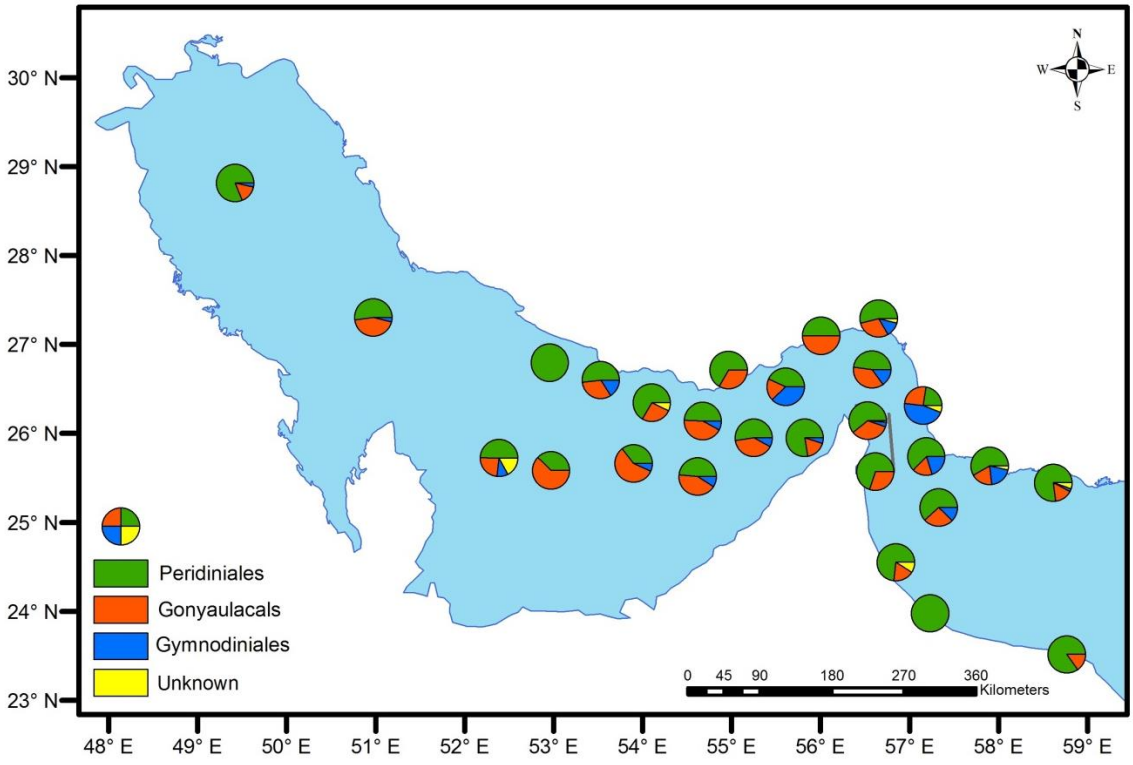

Figure 6: Composition of dinoflagelate orders abundance (%) in different stations of the RSA, Winter 2006

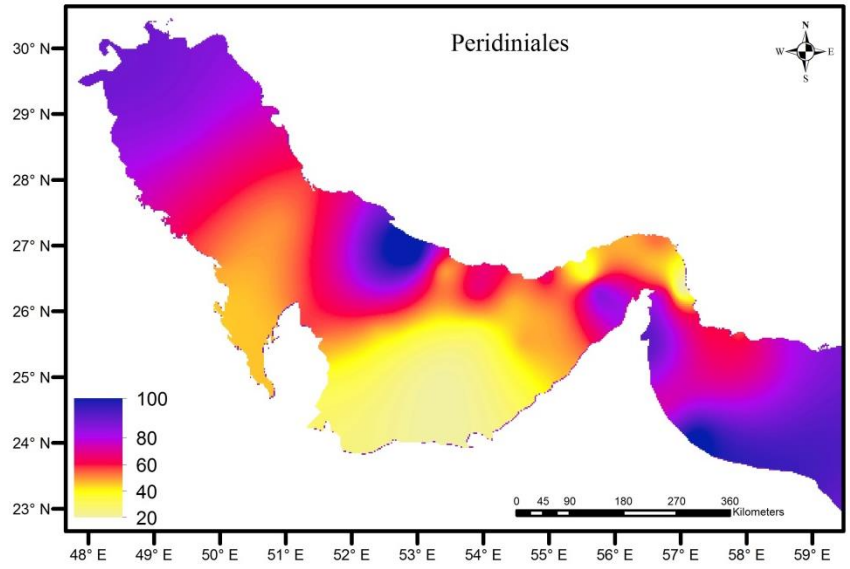

Figure 7: Spatial distribution of Peridiniales abundance (%) in the RSA, Winter 2006

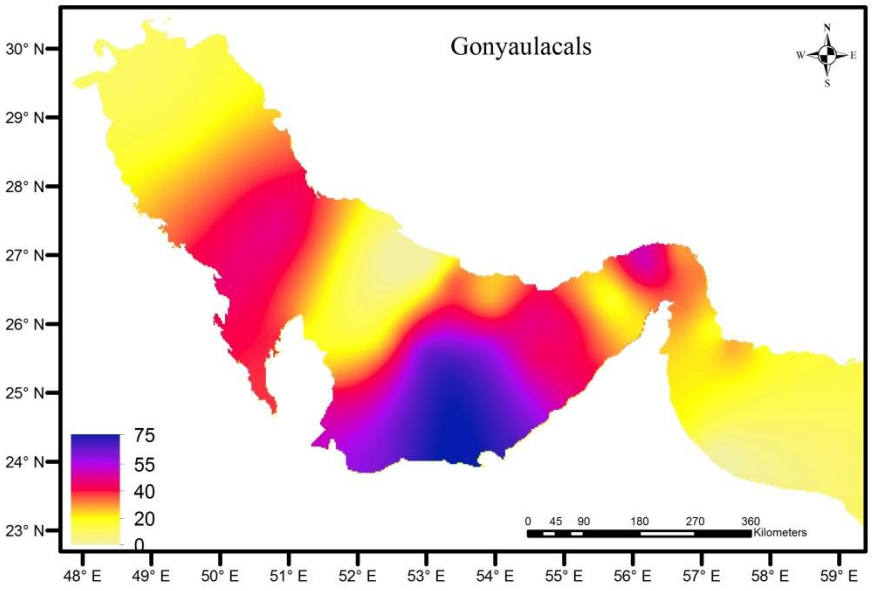

Figure 8: Spatial distribution of Gonyaulacals abundance (%) in the RSA, Winter 2006

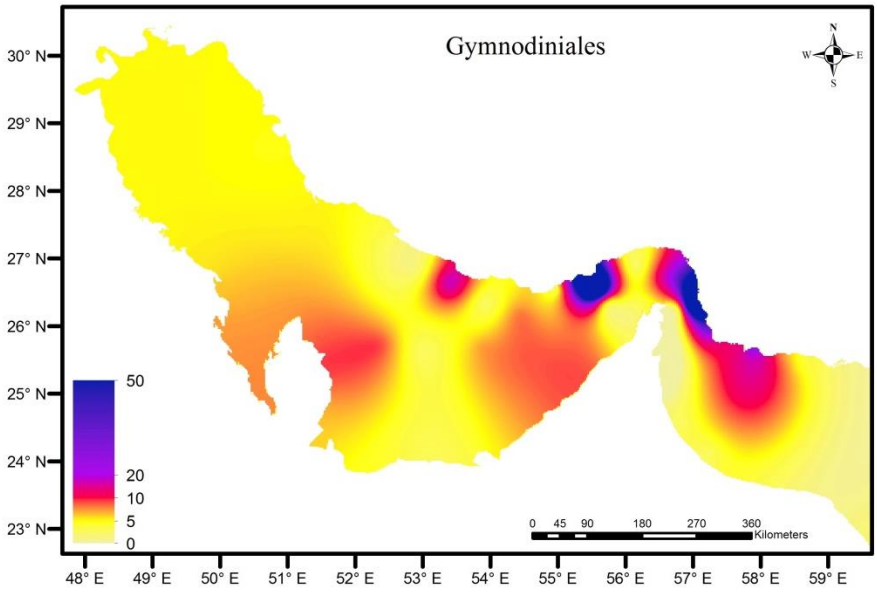

Figure 9: Spatial distribution of Gymnodiniales abundance (%) in the RSA, Winter 2006

The identified dinocysts in the RSA belonged to 11 families. Protoperidiniaceae with 37% cyst abundance was the most abundant family. The second high abundance (22.62%) was recorded for Gonyaulacaceae (Figures 10 and 11). Compositions of abundance (%) in 4 abundant families are compared in different stations (Figure 11). These families comprise a percentage above 9.5% in the RSA.

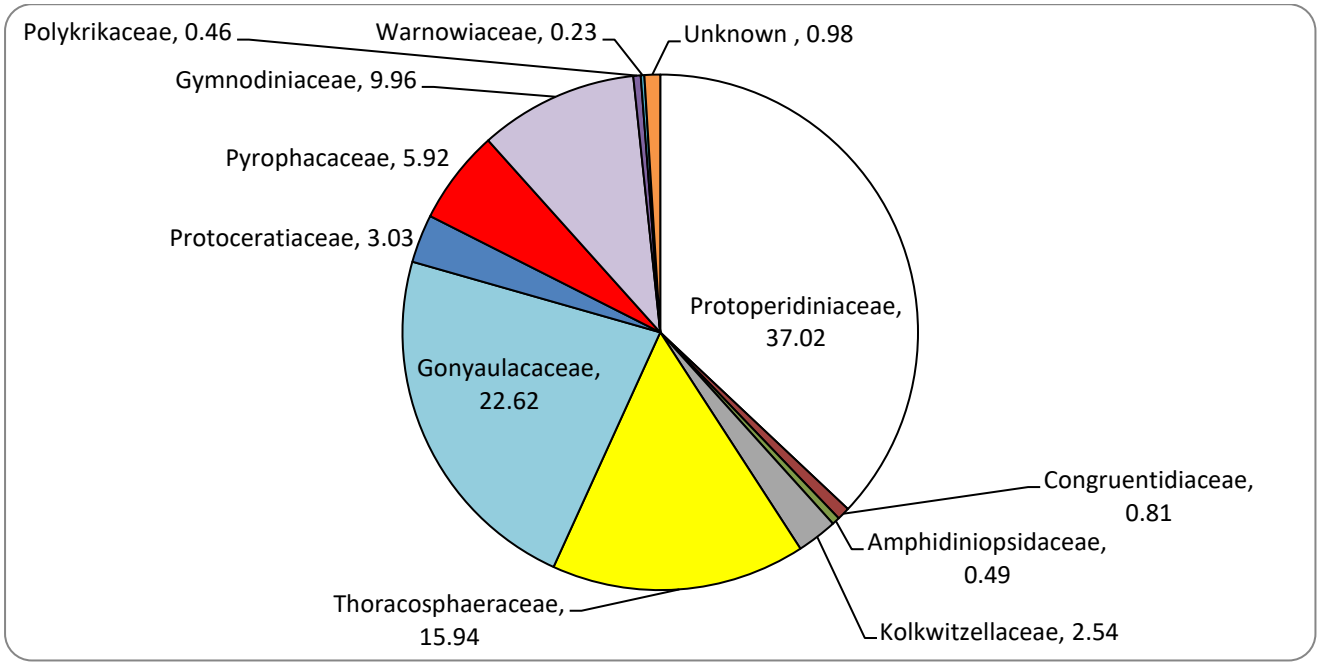

Figure 10: Composition of abundance (%) in dinoflagelate families in the RSA, Winter 2006

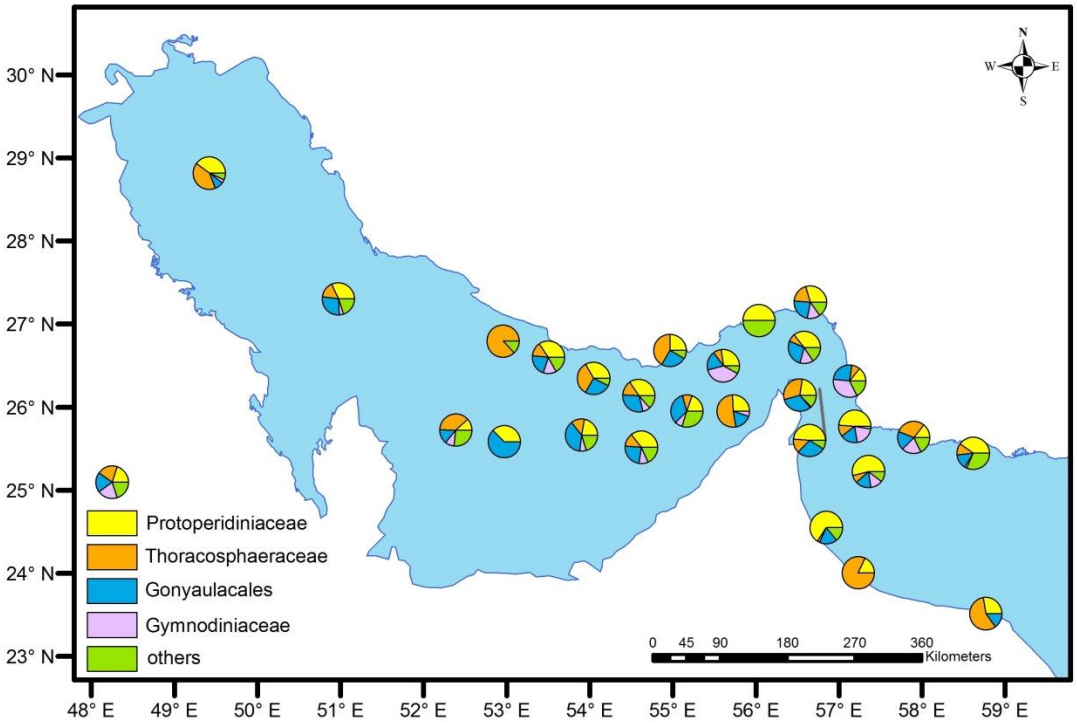

Figure 11: Percentage composition of dinoflagelate families abundance (above 9.5% and others) in different stations of the RSA, Winter 2006

Compositions of families' abundance (%) in each station have been shown in Figures 12 to 18. In station 26a, along Sea of Oman, dinoflagellate cyst belong to three families. The dominant family was thoracosphaeraceae with 56.9% abundance. In this family, in station 26a, two genera were present; namely, *Calciodinellum* and *Alexandrium*. In station 26a, Protoperidiniace represents 27.8% of abundance percentage. In this station, this family comprised of only *Protopredinium* genus. Gonyaulaceace comprised 15.3% of total abundance in the station and *Lingludinium* was the only species of this family (Figure 12A).

The dinoflagellate cysts, in station 25a along Sea of Oman in the RSA, represent two families thoracosphaeraceae with 1.8% abundance and protoperidiniace with 18% abundance.

In station 98, located in Northern part of the Sea of Oman, cyst composition comprised of 8 families. These families with their abundance percentage have been documented in Figure 12C.

The protoperidiniacea with 40% showed the maximum percentage of abundance. The lowest amount of abundance belonged to pyrophycaceae with 1.3% abundance. The family

protoperidiniaceae comprises only one genus of *Protopredinium* and the *Pyrophacuse* was the only genus in the pyrophycaceae. The other family in this station, was Gonyalacacae with two genera; namely, *Bitectatodinium* and *Lingludinium.*

The cysts in station 93 belong to 4 families and one unknown family (Figure 12D). Protoperidiniaceae comprised the highest percentage of the abundance (65.8%) and Thoracosphaeraceae showed the lowest abundance (2.5%).

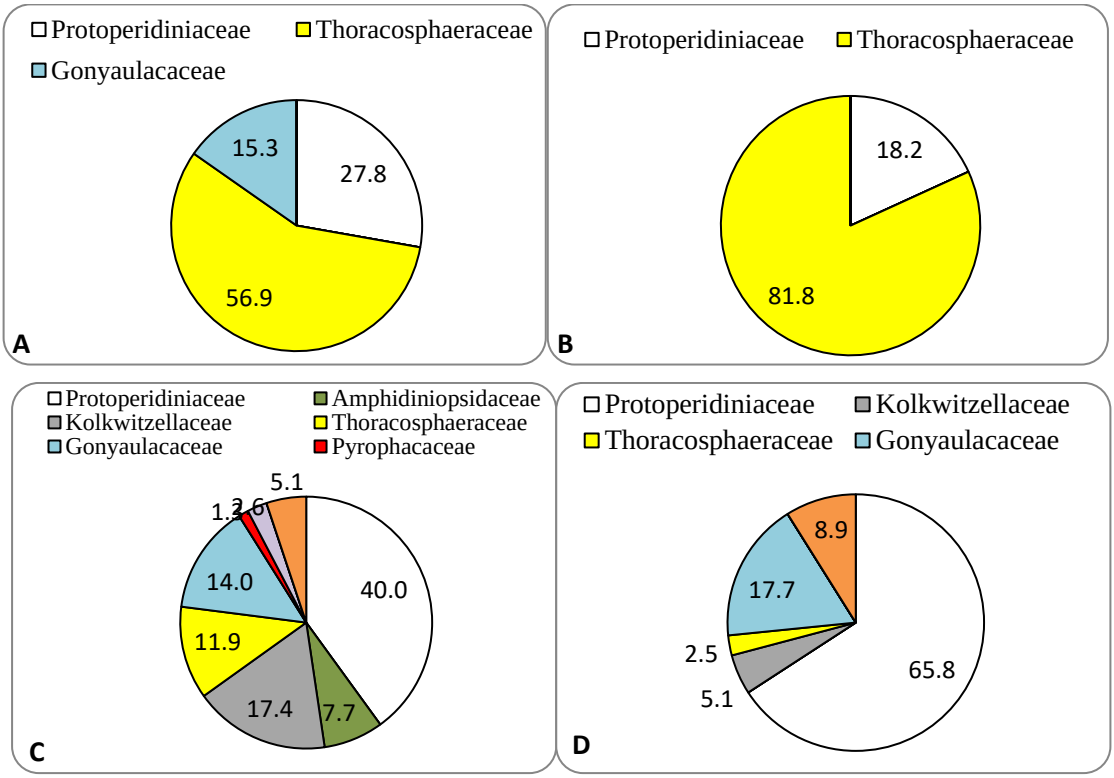

Figure 12: Composition of abundance (%) in dinoflagelate families in the sediment samples of stations of the RSA, Winter 2006. A: station 26a, B: station 25a, C: station 98, D: station 93

The relative abundance of the dinocysts in station 97 was varied between 3.7% (Congruentidiaceae) to 30% (Thoracosphaeraceae). The family Congruentidiaceae represents only *Echinidinium* genus in this station. Thoracosphaeraceae comprised three genera in this station; namely, *Pyrodinium, Alexandrium and Scrippsiella*.

In station 88, dinocysts relative abundance was varied between 0.4% and 53.9%. The highest abundance was recorded for Protoperidiniaceae with one genus (*Protopredinium*). The lowest relative abundance in this station was recorded for Kolkwitzellaceae with genus *Diplopsalis* (Figure 13B).

The Dinocysts in station 21a, located along northern part of the Sea of Oman, represented five known families and one unknown family. The maximum relative abundance was recorded for Protopericiniaceae (48.6%) and minimum for unknown (0.9%). Gymnodiniacea also showed relatively high abundance (19.8%) in this station (Figure 13D).

In station 87, dinocyst families were divers and comprised seven groups. This station is located in the northern part of the Sea of Oman near the Strait of Hormuz. The highest relative abundance was noted in gymnodiniaceae (34.1%) and lowest in Protoceratiaceae with 5.7% (Figure 13C).

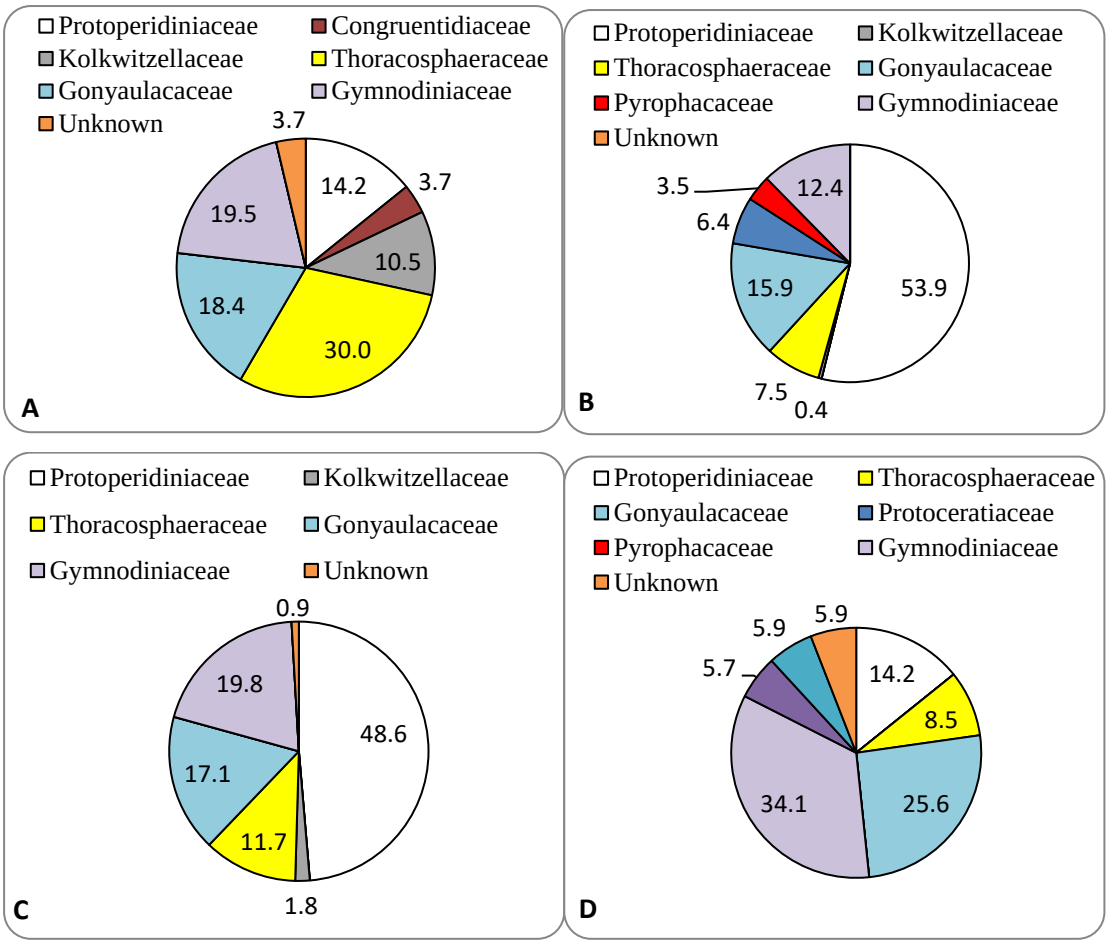

Figure 13: Composition of abundance (%) in dinoflagelate families in the sediment samples of stations of the RSA, Winter 2006. A; station 97, B: station 88, C: station 21a, D: station 87

Dinoflagellate cysts represent six families in station 85, located along the Sea of Oman near the Strait of Hormuz. The Maximum relative abundance (48.8%) was recorded for

Protopericiniaceae and Pyrophacaceae had the lowest abundance (1.3%) in this station (Figure 14A).

Cysts species in station 83 comprised high diversity in families (Figure 14B). This site is located along the Sea of Oman near Strait of Hormuz and cyst species belong to nine families. Both Protopericiniaceae and Thoracosphaeraceae families demonstrated highest similar abundance (31.7%). Gymnodiniaceae and Kolkwitzellaceae families both showed lowest abundance (1.1%). There are two stations located along Strait of Hormuz that sediment samples were collocted for cyst study; namely, stations 14a and 16a. Both of these stations display high diversity in dinocyst families. In station 14a, 9 families of dinocyst are recorded (Figure 14C) and highest relative abundance are recorded for family Protoperidiniaceae with 35.7% abundance. The lowest abundance was recorded for Warnowiaceae with 1.8%.

There are 8 dinocyst families in the sediments of the station 16a as recorded during Winter Cruise 2006. Their abundance varied between 2.6% (Congruentidiaceae and Pyrophacaceae) and the maximum of 29.5%, recorded for Protoperidiniaceae (Figure 14D).

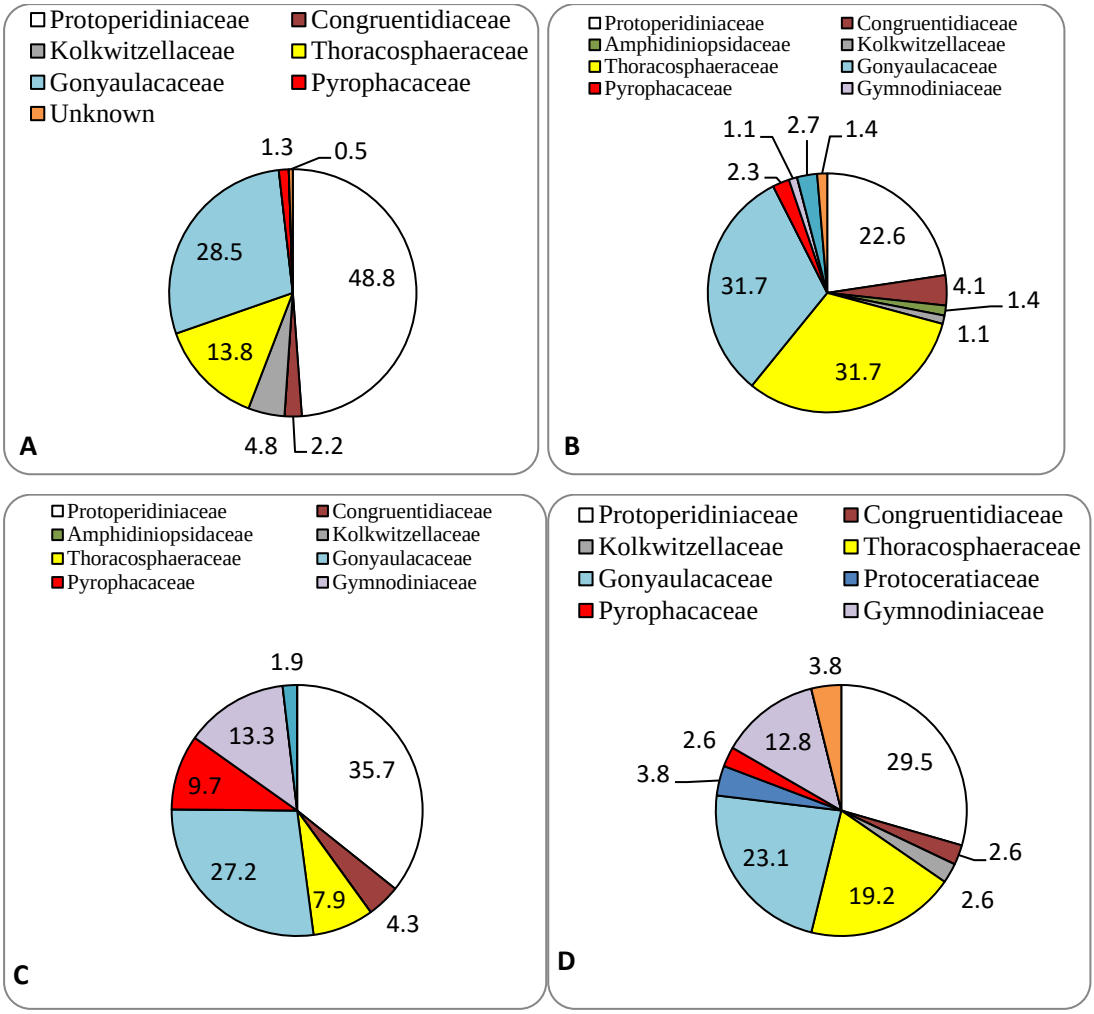

Figure 14: Composition of abundance (%) in dinoflagelate families in the sediment samples of stations of the RSA, Winter 2006.A; station 85 B: station 83 C: station 14a, D: station 16a

In station 79, located in the Inner RSA, near the Strait of Hormuz, cyst composition comprised only two families; namely, Protoperidiniacea and Protoceratiaceae, each of which represented 50% of the abundance (Figure 15A).

The Dinocysts in station 77, located along the Inner part of the RSA, represented four families. Maximum relative abundance was recorded for Thoracosphaeraceae (51.7%) and minimum for Gymnodiniacea (5.2%). Protoperidiniaceae also showed relatively high abundance (25.9%) in this station (Figure 15B).

Cysts species in station 78 comprised five families (Figure 15C). Gymnodiniaceae demonstrated 37.8% of the abundance. Thoracosphaeraceae and Kolkwitzellaceae families showed lowest abundance (8.1%). Cysts species in station 70 comprised four families (Figure

15D). This site is located along Inner part of the RSA. Thoracosphaeraceae demonstrated highest abundance (41.6%) and Pyrophacaceae represented the lowest abundance (8.3%).

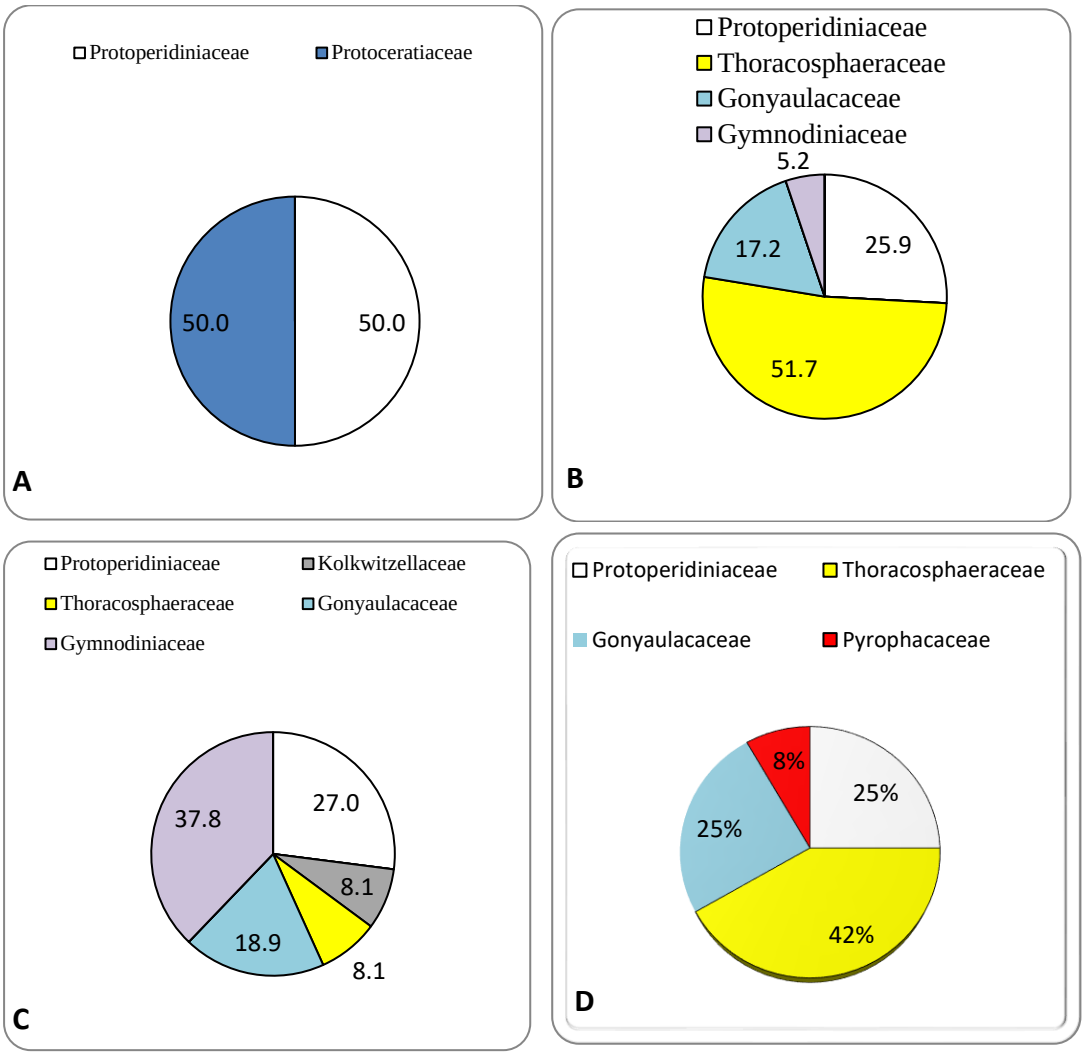

Figure 15: Composition of abundance (%) in dinoflagelate families in the sediment samples of stations of the RSA, Winter 2006. A; station 79, B: station 77, C: station 78, D: station 70

Cysts species in station 72 comprised a high diversity in families (Figure 16A). This site is located in the Inner part of RSA. Gonyaulacaceae demonstrated highest abundance (33.4%). Polykrikaceae showed lowest abundance (0.81%). In station 66, the dinocyst represented five families (Figure 16B) and maximum relative abundance was recorded for Protoperidiniaceae with 35.5%. The lowest relative abundance was verified for Gymnodiniacea (9%). In station 69, the dinocyst located along the Inner part of the RSA, represented seven families. Protoperidiniaceae represented maximum relative abundance with 34.4% (Figure 16C). Minimum abundance belonged to polykrikaceae with 0.7%.

Gonyaulacaceae also showed relatively high abundance (30%) in this station (Figure 16C). In station 56, there were only three known families and one unknown family (Figure 16D). The highest abundance was recorded for both Protoperidiniacea and thoracosphaecaceae families with 33.3%. The least abundance noted 7.4% for unknown species. 37.6% of abundance belonged to the Gonyaulacaceae and least abundance noted for Gymnodiniaceae with 6.7%.

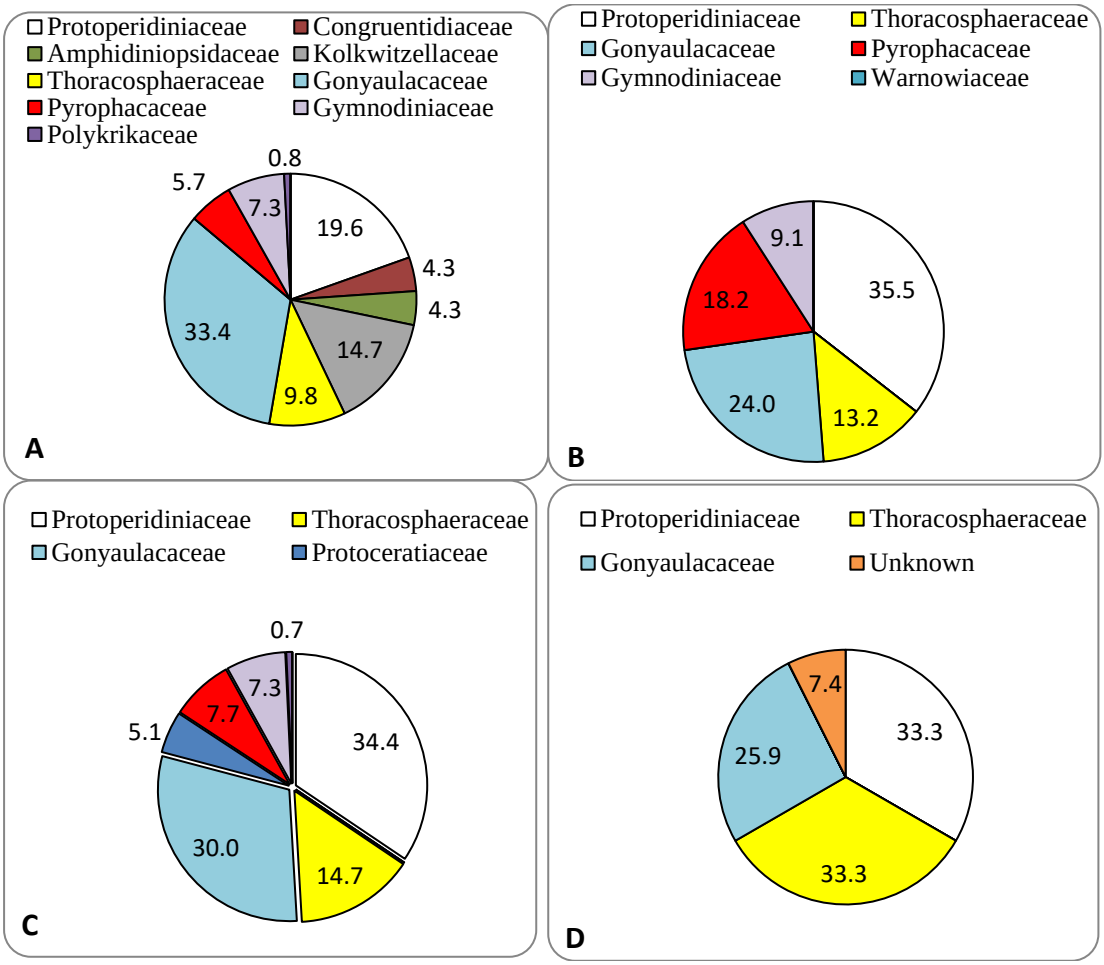

Figure 16: Composition of abundance (%) in dinoflagelate families in the sediment samples of four stations of the RSA, Winter 2006. A; station 72, B: station 66, C: station 69, D: station 56

The dinocyst, in station 50, represented only two families with 62.5% (Gonyaulacaceae) and 37.5% (protoperidiniaceae). Cysts species, in station 55, contained high diversity in families. This site is located in the Inner part of RSA. Protoperidiniaceae demonstrated highest abundance (33.5%). Congruentidiaceae showed lowest abundance (0.24%). There were six families in station 59. The cyst species represented two families in

the station 40; namely, Thoracosphaeraceae with 86.8% and Amphidiniopsidaceae with 13.2% (Figure 17).

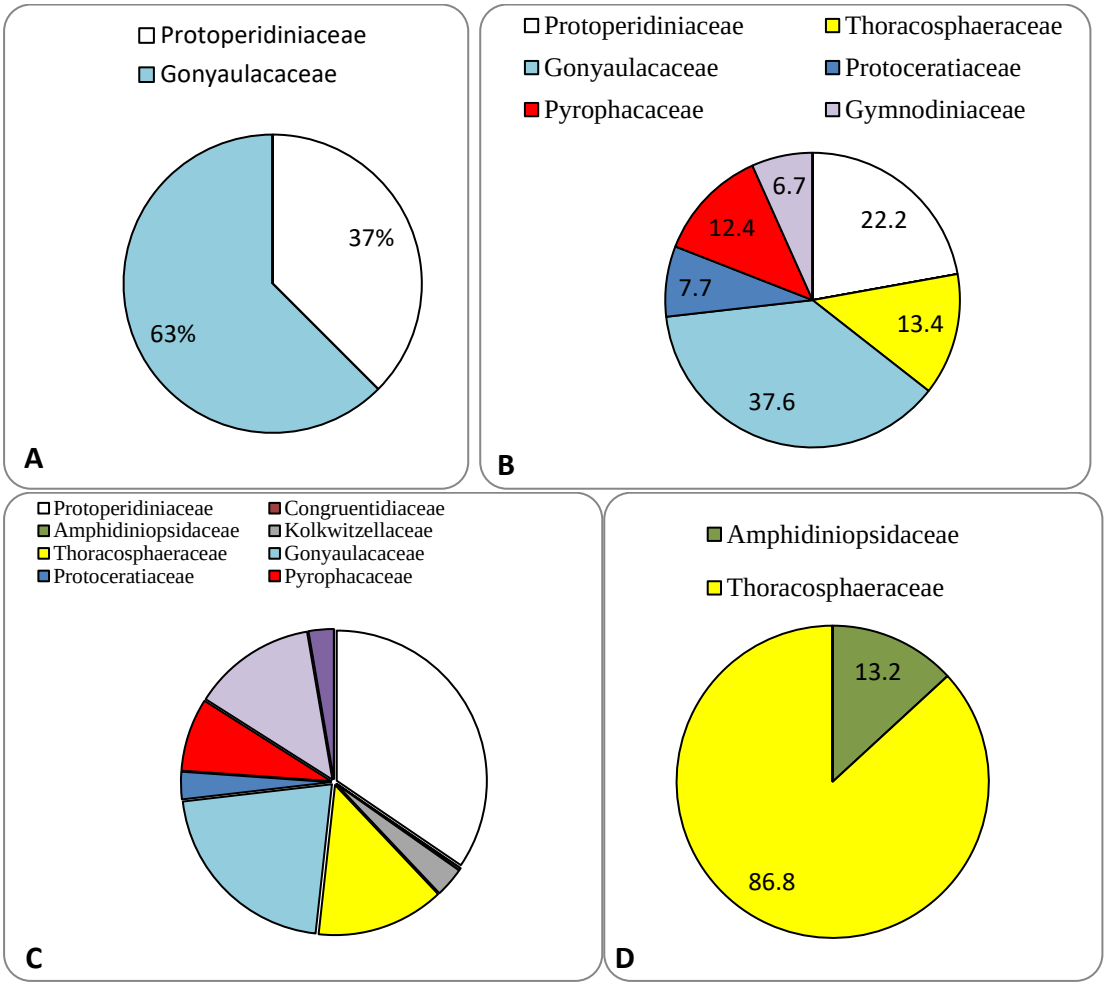

Figure 17: Composition of abundance (%) in dinoflagelate families in the sediment samples of four stations of the RSA, Winter 2006. A; station 50, B: station 59, C: station 55, D: station 40

At station 43, five families represent dinocyst. The highest percentage of abundance was related to Thoracosphaeraceae (37.8%) and the lowest percentage belonged to Pyrophacaceae and Gymnodiniaceae (9.4%). At station 25, there were 6 families with Protoperidiniaceae having the highest percentage (32%). Kolkwitzellaceae and Gymnodiniaceae have the lowest percentage of abundance (3.9%). There were 6 families at station 11, which is the last station in the Inner part of the RSA. The highest percentage of abundance belonged to families with 37% and the lowest percentage belonged to the Protoceratiaceae, Pyrophacaceae and Gymnodiniaceae families with 3.4% of the abundance (Figure 18).

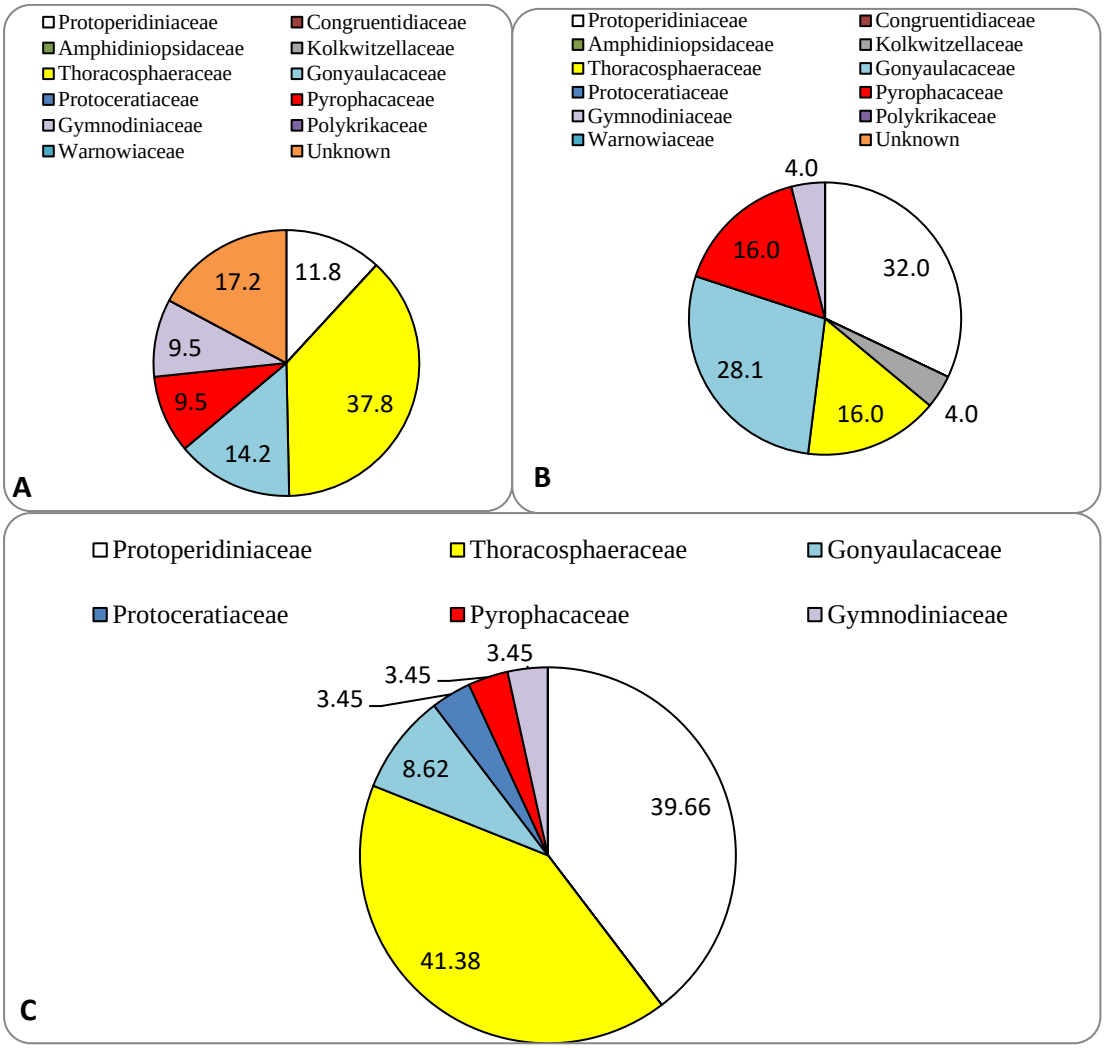

Figure 18: Composition of abundance (%) in dinoflagelate families in the sediment samples of three stations of the RSA, Winter 2006. A; station 43 B: station 25 C: station 11

3.4. Cyst Diversity and Spatial Distribution in the RSA

A total of 30 genera have been identified in the RSA. In phytoplankton cysts, dinoflagellate was dominant group in terms of cyst density and occurrence in the sampling sites. List of identified genus, and their relative abundance, number of species per gram of dry weight of sediments (cysts g^{-1}) and the number of stations that cyst genera have been seen, are given in Table 5. Phytoplankton cyst abundance varied in different genus from one station to another. Among dinoflagellate, six genera contributed to 81.7% of total cyst density in the RSA. These genera are *Protopredinium, Lingulodinium, Gonyaulax Scrippsiella, Pyrophacus, Gymnodinium* and *Cochlodinium*. Distribution of dominant genera along RSA is displayed in Figure 19.

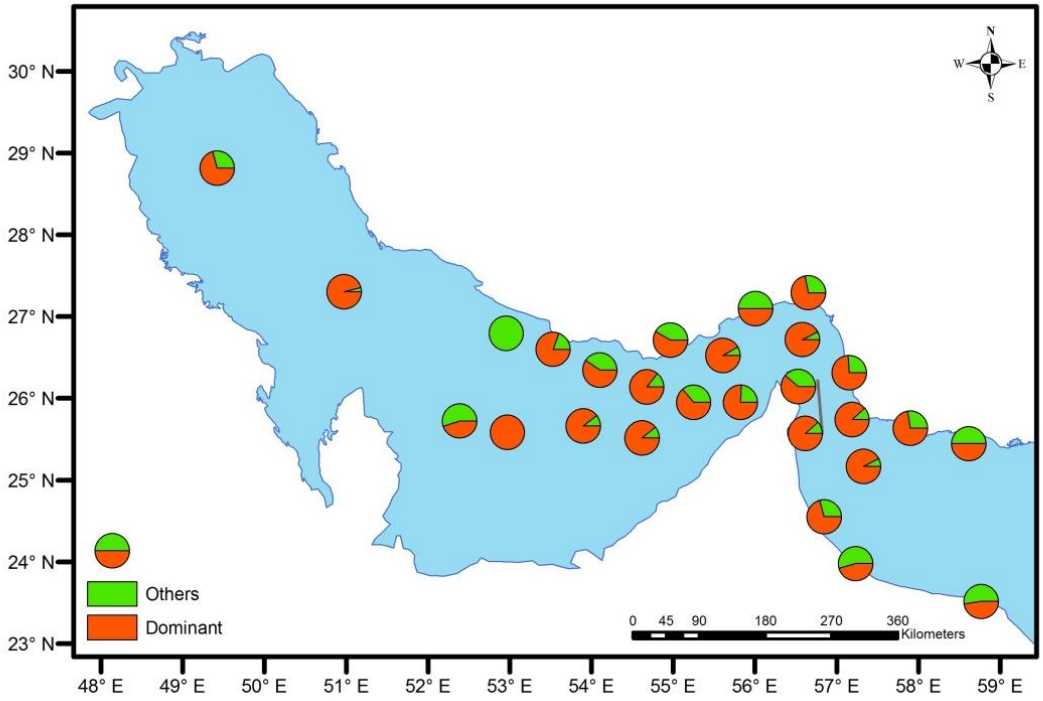

Figure 19: Composition of abundance (%) of top six dominant genera with others in the different stations of the RSA, Winter 2006

Within 30 genera of phytoplabkton resting cyst, *Protopredinium* with 26 species was the most diverse genus and showed the maximum abundance 36.57% (Table 5). The *Protopredinium* species was widely distributed along the Inner part of RSA and Sea of Oman and has been observed in almost all stations. The highest relative abundance of the genus was in station 88, with 53.9% of the total abundance (Figure 20). In this genus, the highest relative abundance has been attributed to the *P. avellana* with 5.8% of total abundance. *P. avellana* was also the third dominant species within all dinoflagellte species (Table 6). *P. avelana* was a common species (more than 50% occurrence in samples of the RSA) and found in 16 stations of tested sediments. This species had higher density in stations 66 and 88.

Protoperidinium is the dominant heterotrophic group in extant dinoflagellate cyst assemblages (Morquecho *et al.*, 2009). The diverse species of *Protoperidinium* were predominately recorded in both planktonic and sediment samples in many areas including Andaman Sea, south-west Africa, Southern California, and the Sea of Oman (Marret and Zonneveled, 2003; Attaran-Fariman, 2010; Myat *et al.*, 2012). High abundance of heterotrophic *Protopredinium* cyst may be the result of increase in diatom production (Matsouka 1999). Dale (2001) also suggested that reduction in the light intensity causes the

increase of heterotrophic forms. *P. avellana* has also been recorded as common species in other tropical areas such as Gulf of California (Martínez-Hernández and Hernández-Campos 1991).

Lingulodinium is the second dominant genus (12.61%) with 2 species in the RSA. 11.75% of the total abundance has been attributed to *Lingulodinium polyedrum* with highest cyst concentration (21.69 cyst g^{-1}dws) in station 55, in the depth of 86m at the Inner part of the RSA. The highest relative abundance (62.5%) of the genus in coamparison with other genera was in station 50 (Figure 21). *Lingulodinium* sp. comprised only 0.81% of abundance and found in 4 stations. Among phytoplankton cysts, *L. polyderum* has been recorded as the dominant taxa in the RSA (Table 6). This species is potentially HAB forming Species and has been seen in 22 stations. Although the *Prtotopredinium* genus has the highest relative abundance among the genera, due to the number of presented species in this genus (26), the highest species abundance was not recorded for this genus. *Lingulodinium* cysts are abundant in a variety of nutrient rich environments and salinity of brackish environments to the normal (Wall *et al.* 1977). This species has been recorded 10-50% in the sediment of equatorial Atlantic upwelling (Harland, 1983). Downie *et al.* (1971) found high cyst concentration (10^4cyst/g) in the offshore sediment samples of Morocco. Targarona *et al.* (1999) documented *Protopredinium spp* and *L. polyedrum* as dominant cysts underlying upwelling system.

Gonyaulax/ Spiniferites with 8.85% abundance was recorded as the third dominant of dinocyst genus and also among total phytoplankton cysts. In this genus, 11 species were found in 21 stations in the RSA. The special distribution of the genus shows that the *Gonyaulax* spp has the highest relative abundance (28.4%) in station 59 (Figure 22). The highest density was also observed in stations 59 and 83 with an average of 28.5 cyst/g and 23.8 cyst g^{-1}dws.

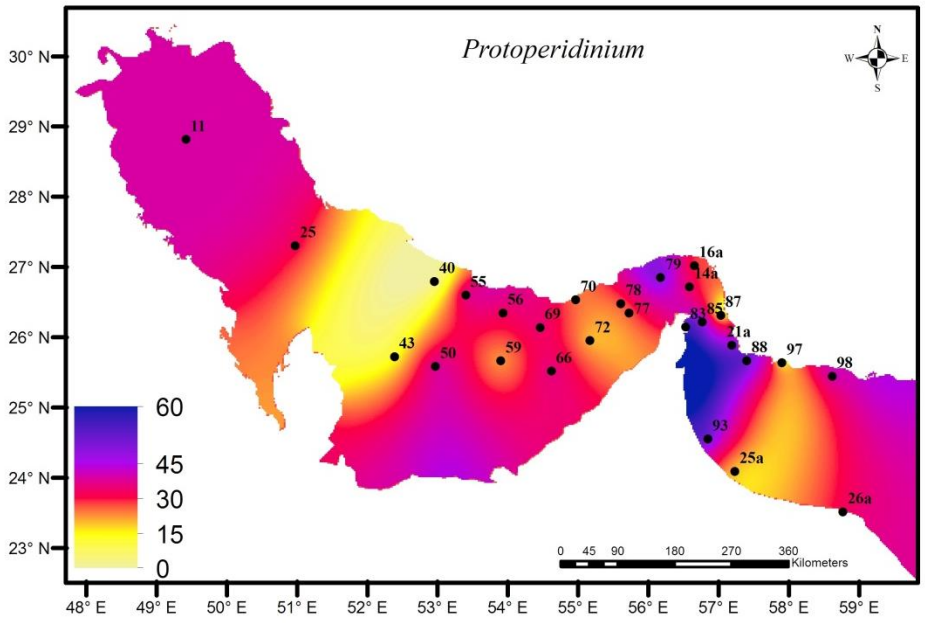

Figure 20: Spatial distribution of relative abundance of *Protopresinium* spp along RSA, Winter 2006

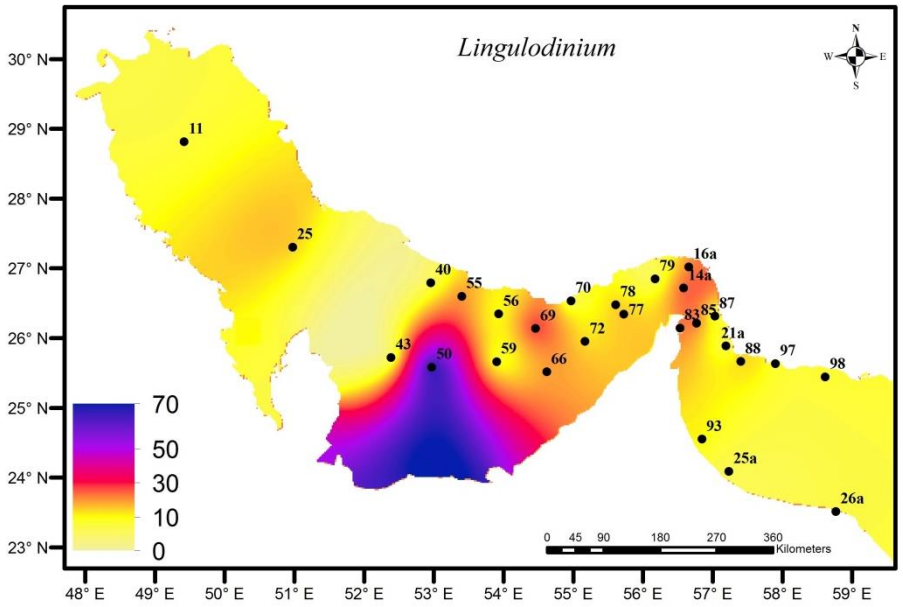

Figure 21: Spatial distribution of *Lingulodinium* genus relative abundance (%) in the different stations along RSA, Winter 2006

Within the *Gonyaulax*, the highest cyst concentration in stations was noted for *S. ramosus* (*Gonyaulax spinifera complex*) with an average of 10.36 cyst g^{-1}/g in station 88. This species has 1.58% of total phytoplankton cysts abundance in the RSA (Table 6). *S.*

ramosus has been reported from a broad range of environments from Antarctic to subtropical regions. High relative abundance of this species has been reported from China and Arabian Sea (Marret and Zonneveld, 2003). This species is considered as a cosmopolitan species that can be found in a broad range of temperatures, salinities, and phosphate and nitrate concentrations. However, in the RSA, the highest total abundance within *Gonyaulax spinifera complex* group belonged to *S. mirabilis* with 2.11% of total phytoplankton cyst abundance. Total cyst concentration for this species was 22.06 cyst g^{-1}dws. The highest relative abundance of this species has been recorded from sediment of oligotrophic/mesotrophic environment and also some eutrophic environments (Marret and Zonneveld, 2003). This cyst has already been reported from the Sea of Oman in high concentrations too (Attaran-Fariman and *et al*., 2012) and Arabian Sea (Zonneveldand Brummer, 2000). This cyst species has been considered as temperate to tropical species.

G. membranacea (S. membranaceus) with 1.59% abundance of total phytoplankton cysts and 16.66 cyst g^{-1}dws showed high concentration among *G.spinifera* complex group of the RSA. This species has also been reported from temperate to tropical areas (Wall *et al.*, 1977). The cyst is distributed in the Sea of Oman and Arabian Sea (Bradford and Wall, 1984; Attaran Fariman *et al.*, 2012). Highest relative abundance for this species has been documented from sediment of oligotrophic/mesotrophic environments (Marret and Zonneveld, 2003).

Scrippsiella spp with 7.15% abundance of total phytoplankton cysts was among the dominant genera in the RSA. The highest relative abundance of the genus was observed in stations 77 and 25a with 27.6% and 27.3% (Figure 23). In this genus, five cyst species have been found in the sediments of 27 stations along the RSA in Winter 2006. These cysts concentration and occurrence varied from one station to another; *S. trifida* has been recorded only at one site (Station 40) with 0.1% of total abundance. *S. irregularis* has been found in 11 stations with relative abundance of 3.34% and highest average concentrations of the cyst (9.09 cyst g^{-1}dws) in station 88. *S. precaria* was recorded only in 3 stations with 0.27% of relative abundance and highest cyst density (1.33 cyst g^{-1}dws) was noted in station 66. *S. regalis* with 0.8% abundance has been recorded at two sites with highest average concentration (0.61 cyst g^{-1}dws) in station 72.

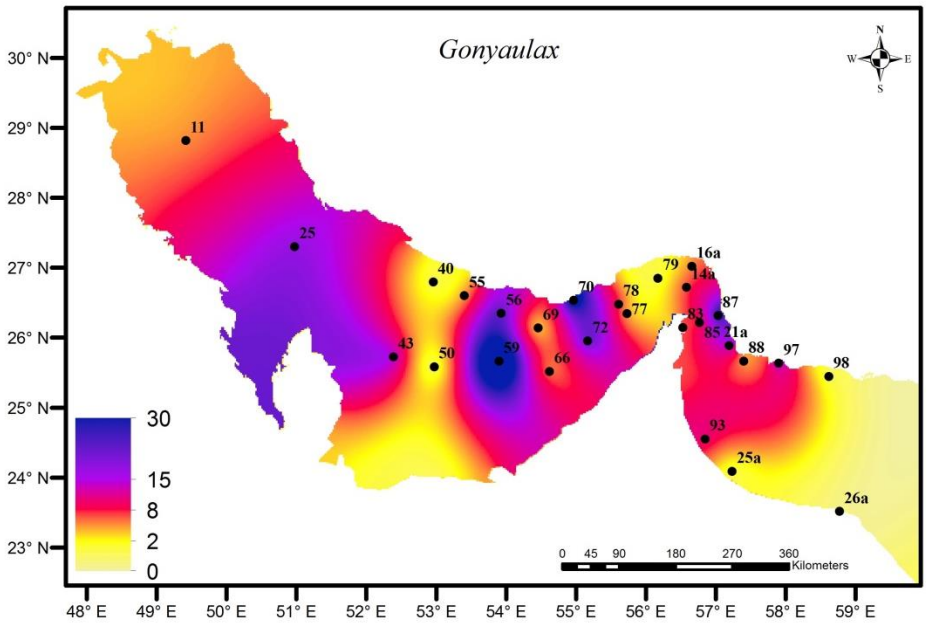

Figure 22: Spatial distribution of the *Gonyaulax* spp abundance (%) in different stations of RSA, Winter 2006

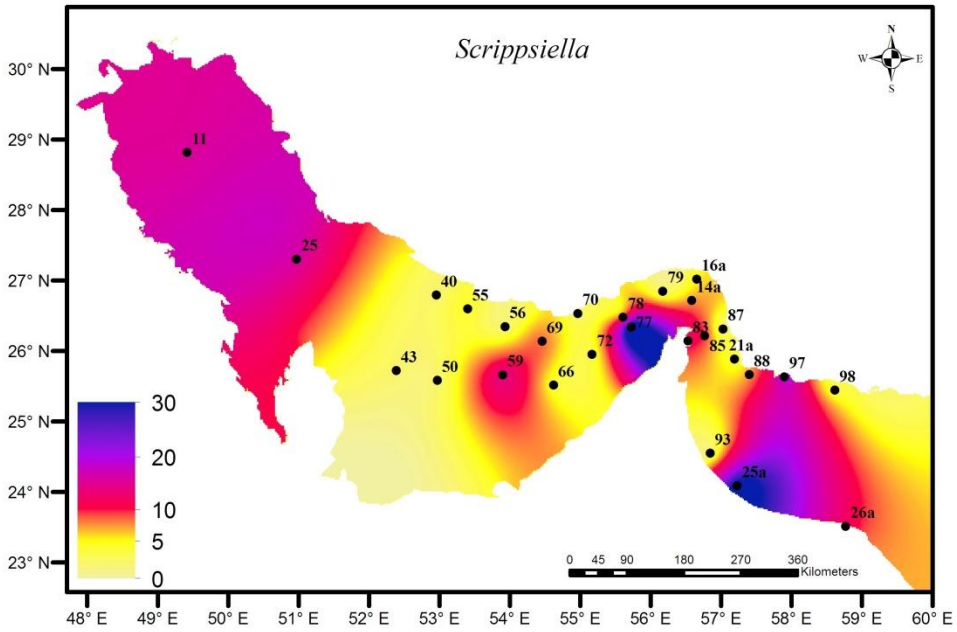

Figure 23: Spatial distribution of the *Scrippsiella* spp abundance (%) in different stations of RSA, Winter 2006

S. trochoidea, which is potentially harmful species within this genus, has widely distributed along RSA and recorded from 15 stations (Figures 14, 23 and Table 6). This

calcareous cyst accounted for 3.46% of the total cysts abundance in the RSA with highest average cyst concentration (5.56 cyst g^{-1}dws) in station 85 (Figures 14 and 23).

Scrippsiella diversity and abundance, in tropical and subtropical reigns, is higher in comparison with those of the other areas (Vink, 2004). The genus contains about 20 extant species, nine of which are known to produce calcareous resting cyst. Five cysts have been recorded from RSA in Winter 2006. However, the number of species presented in the RSA is more. Attaran-Fariman (2007) found 8 *Scrippsiella* cyst species in the sediment of Sea of Oman from nine shallow stations (1m to 6m depth) in Winter 2004. These cysts belonged to *S. lachrymose, S. throcoidea, S. precaria, S. irregularis, Scrippsiella sp1, Scrippsiella sp2, Scrippsiella sp3,* and *Scrippsiella sp4*. Attaran-Fariman (2016) has also recorded 9 species of cysts in the sediment samples collected from 47 stations (1m to 28m depth) along Sea of Oman during four seasons. These cysts belonged to *S. lachrymose, S. throcoidea, S. precaria, S. irregularis, S. romanii*, and *S. pentagonica,* and three species at the genus levels. *Scrippsiella* spp, with 8 species, comprised up to 75% of cyst flora at shallow neritic stations of Sea of Oman (Attaran Fariman 2007). In this study, *S. regalis* and *S.trifida* were found in low abundance and low number of occurrence (one station) in the samples of RSA, which have not previously been reported from RSA.

Among top dominant genera, *Pyrophacus* with only one species comprised 5.9% of the total abundance in the RSA. This genus has the *Pyrophacus steinii* and showed the high concentration (14.66 cyst g^{-1}dws) with a relative abundance of 18.2% at station 66 along Inner part of the RSA (Figure 24). *P. steinii* is considered to be typical neritic cyst flora of the tropical and subtropical areas that might have reduced Sea Surface Salinity (SSS). (Bradford and Wall, 1984; Yoo, 1991; Dale *et al.*, 1999). However, this is not limited to shallow coastal area (Marret, 1994). The highest cyst abundance found in station 66 with 45m depth in the Inner part of the RSA. Attaran-Fariman *et al.* (2012) have recorded low abundance of species from Chabahar bay in depth of 3m. High abundance of this species has been reported from the I-RSA and low abundance from northern part of the Arabian Sea (Bradford and Wall, 1984). The species in low abundance has also been reported from the northern part of the Sea of Oman (Attaran-Fariman *et al.*, 2012; Attaran-Fariman 2016). Sirivilai *et al.* (2012) have demonstrated the cyst of *P. stenii* from the Gulf of Thailand as dominant species. Highest relative abundance of species has been documented in oligotrophic environments (Marret and Zonneveld, 2003).

Gymnodinium spp with 6 species comprised 5.46% of the total abundance and found in 15 stations along RSA in Winter 2006 (Table 5). These microreticulate cysts species are; *G. catenatum, G. noleri* (0.34%), *G. trapeziforme* (0.6%), *G. microreticulatum* (0.95%), *G. inusitatum* (0.1%) *and Gymnodinium* sp (0.095%). Among these, *G. catenatum,* which is potentially a PSP toxin producer with 3.36% of the total phytoplankton, represented the highest abundance with a concentration of an average 9.9 cysts per gram of dry sediment. The cyst species is limited to the tropical and subtropical areas with high productivity and deep vertical mixing (Marret and Zonneveld, 2003). In the RSA, cyst has highest relative abundance in station 88, located in Sea of Oman (Figure 25) with 65m depth. In the Sea of Oman, circulation of water is strongly affected by seasonal monsoon (South West Monsoon; SWM and North East Monsoon; NEM). A circulation that may explain the higher cyst concentration of the species in the Sea of Oman. This cyst has not been reported from the Sea of Oman in the study of Attaran-Fariman in the sediment samples collected in 2004 (Attaran-Fariman, 2007), most probably due to the limited number of coastal samples collected from depth of 1m to 4m. However, Attaran Fariman (2016) found the cyst of this species in the sediment samples of the Sea of Oman. *G. trapeziforme* cyst in the sediment sample of the RSA in Winter 2006 showed low abundance within this genus, whereas it has been recorded as a dominant species of the genus in the Sea of Oman (Attaran Fariman 2012; 2016). The type locality of this species is northern part of the Sea of Oman along Iranian coast. *G. inusitatum* with polygonal microreticulate cyst wall is reported for the first time from the RSA. The cyst of species was reported from Yellow Sea off China for the first time (Gu *et al.* 2013). It has been documented that motile cells of *G. inusitatum* are similar to those of *G. trapeziforme,* but their LSU sequence and the shape of cyst stage are different (Gu *et al.* 2013).

The genus *Cochlodinium* with only one species has been recorded from 11 stations (Table 5). *Cochlodinium polykrikoides* comprised 4.41% of the total phytoplankton abundance in the RSA in Winter 2006 (Table 6). The highest relative abundance (27%) was observed in station 78 (Figure 26). The cyst of this species was morphologically investigated for the first time from natural sediments of Korean coastal sediment (Li *et al.* 2015). Prior to this, most of the studies on the resting cysts have not offered the proper evidence on cyst identification (Orlova *et al.* 2004, Kim *et al.* 2007, Pospelova and Kim 2010). Before 2006, cyst of *C. polykrikoids* was not recorded in the sediments of the Sea of Oman and Inner RSA.

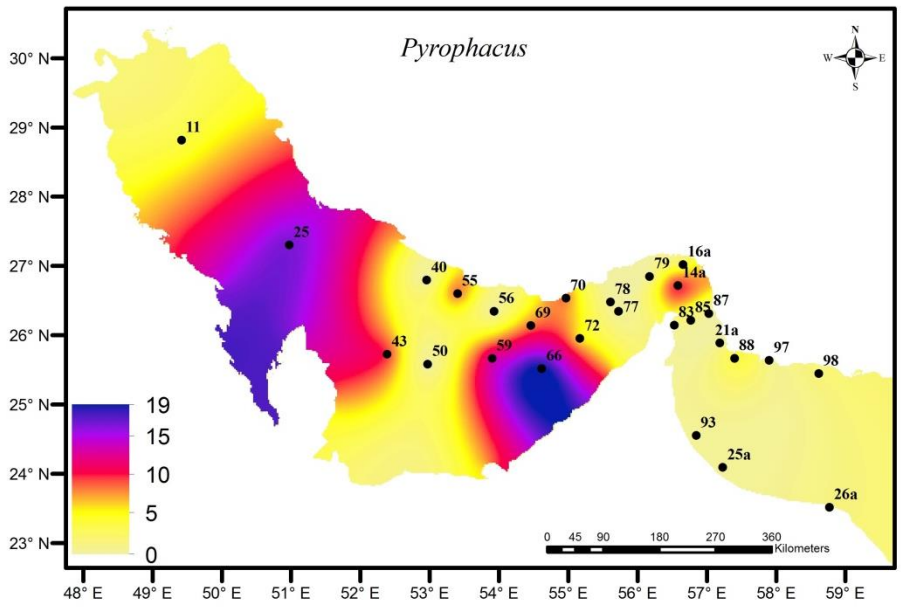

Figure 24: Spatial distribution of the *Pyrophacus* abundance (%) in different stations of RSA, Winter 2006

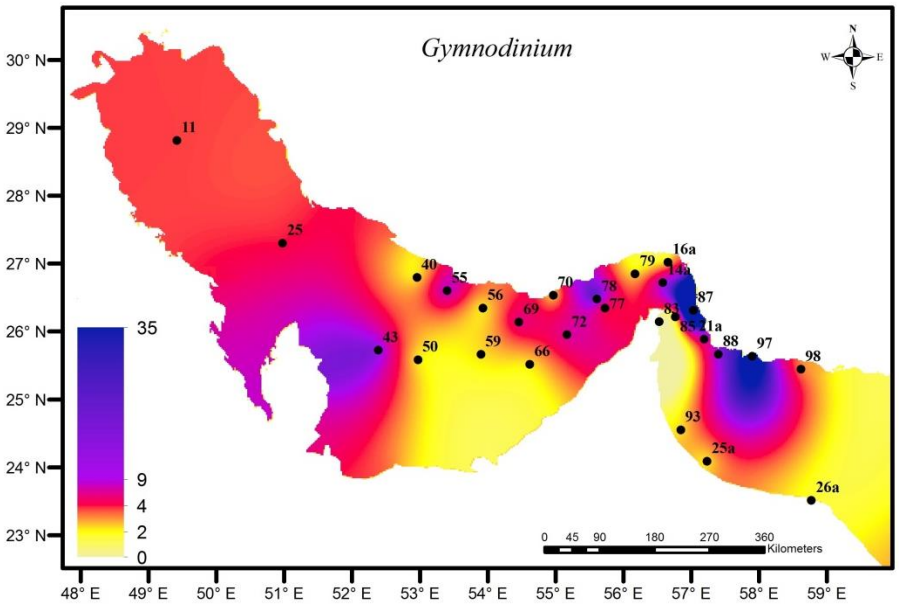

Figure 25: Spatial distribution of the *Gymnodinium* spp abundance (%) in differen stations of RSA, Winter 2006

In the study of Attaran-Fariman (2007), sediment collected in 2004 from limited stations along northern part of the Sea of Oman. The cyst of this species was not observed and later in 2013, cyst has been observed in the sediment of the Sea of Oman for the first time (Attaran Fariman *et al.*, 2013). The present investigation on the RSA sediments collected in

2006 revealed useful information on distribution of *C. polykrikoids* and its role as seed bank that probably initiated a dense bloom in 2008-2009.

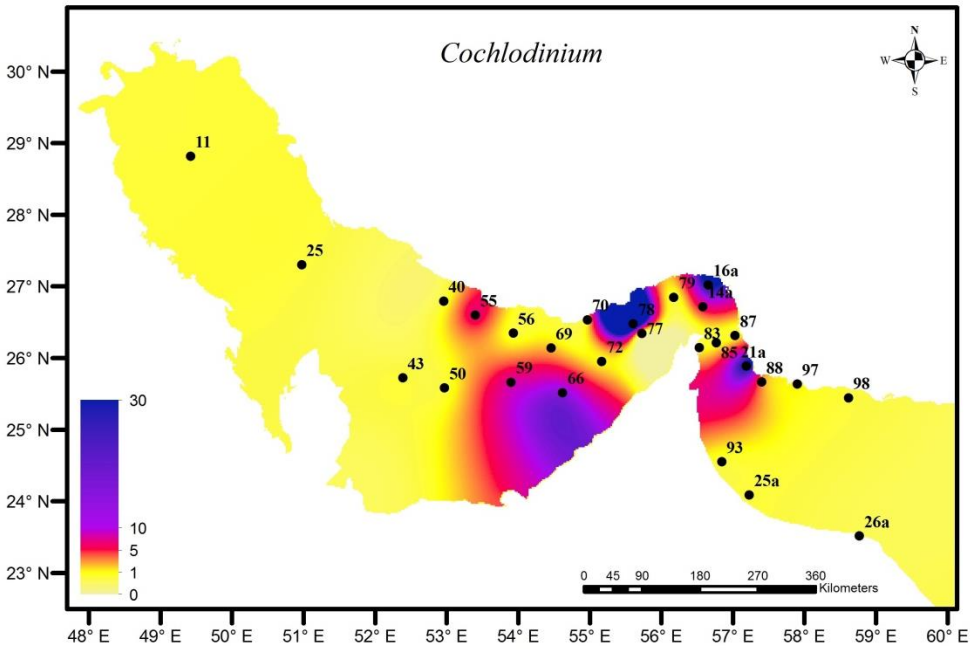

Figure 26: Spatial distribution of the *Cochlodinium* abundance (%) in different stations of RSA, Winter 2006

Table 5: Phytoplankton cyst genera in the RSA, abundance (%), number of species in genus, number of cyst genus occurrence in sampling stations

Genus	No. Species	Abundance %	No. Occurrence in Stations
Protoperidinium	26	36.57	26
Niea	1	0.13	1
Echinidinium	2	0.80	6
Islandinium	1	0.45	4
Archaeperidinium	1	0.03	1
Diplopsalis	3	1.77	8
Diplopleta	2	0.75	3

Table 5. Contd.

Genus	No. Species	Abundance %	No. Occurrence in Stations
Pyrodinium	1	2.42	9
Alexandrium	6	2.80	11
Scrippsiella	5	7.15	18
Calciperidinium	1	0.48	5
Calciodinellum	2	1.34	4
Leonella	1	0.37	4
Bicarinellum	1	0.02	1
Pentapharsodinium	2	1.22	8
Bitectatodinium	1	0.44	2
Nematosphaeropsis	1	0.50	4
Gonyaulax	11	8.85	18
Protoceratium	1	3.00	7
Lingulodinium	2	12.61	22
Pyrophacus	1	5.87	15
Gymnodinium	6	5.46	15
Cochlodinium	1	4.41	11
Polykrikos	1	0.46	4
Warnowia	1	0.13	2
Biecheleria	1	0.10	1
Paralia	1	0.98	10
Chattonella	1	0.56	5
Heterosigma	1	0.10	3

Table 6: Abundance of phytoplankton taxa that contribute more than 1% of total cyst assemblage in the RSA, Winter 2006. Codes are used in multivariate analysis

Cyst Species	Code	%	Cyst Species	Code	%
Lingulodinium polyedrum	*Lipo*	11.76	***Spiniferites mirabilis***	*Spmi*	2.11
Pyrophacus steinii	*Pyst*	5.87	***Protoperidinium conicoides***	*Prcd*	2.03
Protoperidinium avellana	*Prav*	5.80	***Protoperidinium cf. punctulatum***	*Prpu*	2.03
Cochlodinium polykrikoides	*Copo*	4.42	***Protoperidinium shanghaienseB***	*PrsB*	1.88
Scrippsiella trochoidea	*Sctr*	3.46	***Gonyaulax membranacea***	*Gome*	1.59
Gymnodinium catenatum	*Gyca*	3.36	***Protoperidinium sp1.***	*Psp1*	1.85
Scrippsiella irregularis	*Scir*	3.34	***Protoperidinium latissimum***	*Prla*	1.59
Protoperidinium claudicans	*Prcl*	3.22	***Spiniferites ramosus***	*Spra*	1.58
Protoceratium reticulatum	*Prre*	3.00	***Gonyaulax cf. scrippsae***	*Gosc*	1.48
Protoperidinium leonis	*Prle*	2.84	***Alexandrium affins***	*Alaf*	1.47
Protoperidinium denticulatum	*Prde*	2.82	***Protoperidinium shanghaiense A***	*PrsA*	1.24
Pyrodinium bahamense	*Pyba*	2.42	***Diplopsalis lenticula***	*Dile*	1.27
Protoperidinium conicum	*Prcm*	2.21	***Calciodinelum opresom***	*Caop*	1.15
Protoperidinium compressum	*Prco*	2.14	***Protoperidinium sp7***	*Psp7*	1.11

3.5. Dinocyst Diversity

Totally, 88 dinocyst taxa belonging to 26 genera were identified from 27 samples along Inner RSA and the Sea of Oman in Winter 2006. Of which, 68 taxa belong to the species level, 15 taxa to the genus level and 6 cysts remain unknown. Shannon-Wiener Diversity (SWD) index usually did not follow the pattern of cyst concentration in the RSA (Figure 27) and generally followed the pattern of species richness (Figure 28). The station with highest taxa richness has a highest Shannon Diversity Index. Diversity was varied between 1.17 to 3.22 in the RSA. The highest diversity has been observed in station 72, while the lowest recorded in station 79. The highest taxa richness was documented in station 72 with Margalef Richness Index (Dmg) 8.68 and maximum number of species (29 taxa) (Figure 28). In this site, the species was almost evenly distributed with 0.96 Pielou's Index (Figure 29). This

Index varied between 0-1; less evenness in the communities, the index is more close to zero. In the RSA, station 26a showed the highest evenness with only 8 species (Table 7). The diversity depends on species richness and evenness. It was remarkable that, although in station 83, a high species richness (26 taxa) and Dmg of 7.86 were observed, but a high diversity was not recorded in comparison with other stations; the station had a 0.89 evenness.

Table 7: Dinoflagellate cyst Diversity in different Stations in the RSA, Winter 2006; Species Diversity (H') Species Richness (Number of species: S, Margalef Index; Dmg) Evenness (Pielou's index; E)

Stations No.	Shannon-Wiener Index (H´)	Margalef Index (Dmg)	Pielou's Index	Number of Species (S)
26a	1.88	2.75	0.97	8
98	2.69	5.24	0.90	20
25a	1.79	3.69	0.92	8
93	1.66	3.11	0.80	8
97	2.74	5.52	0.92	8
88	3.06	4.32	0.96	24
21a	2.83	5.55	0.93	21
87	1.79	2.96	0.86	8
85	2.64	4.81	0.87	21
83	2.92	7.86	0.89	26
14a	2.67	4.76	0.89	20
16a	2.72	5.10	0.89	21
79	1.17	2.26	0.84	4
77	2.44	4.05	0.93	14
78	2.06	3.03	0.94	9
70	1.42	2.33	0.88	5
72	3.22	8.68	0.96	29

Table 7. Contd.

Stations No.	Shannon-Wiener Index (H´)	Margalef Index (Dmg)	Pielou's Index	Number of Species (S)
66	2.46	3.64	0.87	17
69	2.71	5.67	0.84	25
56	2.01	3.46	0.96	8
59	2.80	4.32	0.94	20
50	0.66	1.22	0.95	2
55	3.03	6.18	0.88	31
40	0.39	1.08	0.56	2
43	1.88	2.75	0.97	7
25	2.17	3.57	0.94	10
11	3.10	6.97	0.97	24

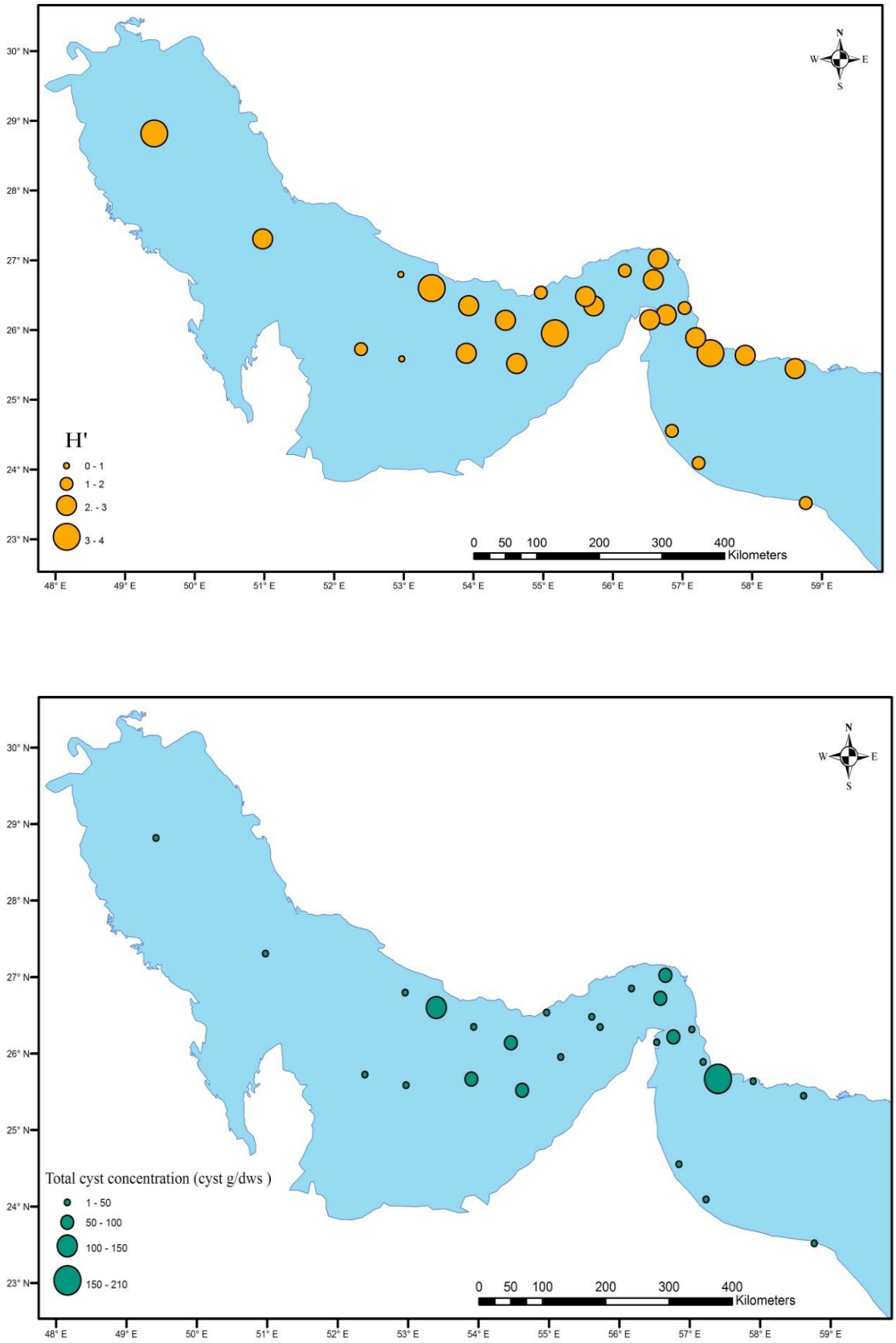

Figure 27: Distribution of Dinocyst Diversity (H') (upper map) and total dinocyst concentration Cyst g^{-1}dws (lower map) in different sites at RSA, Winter 2006

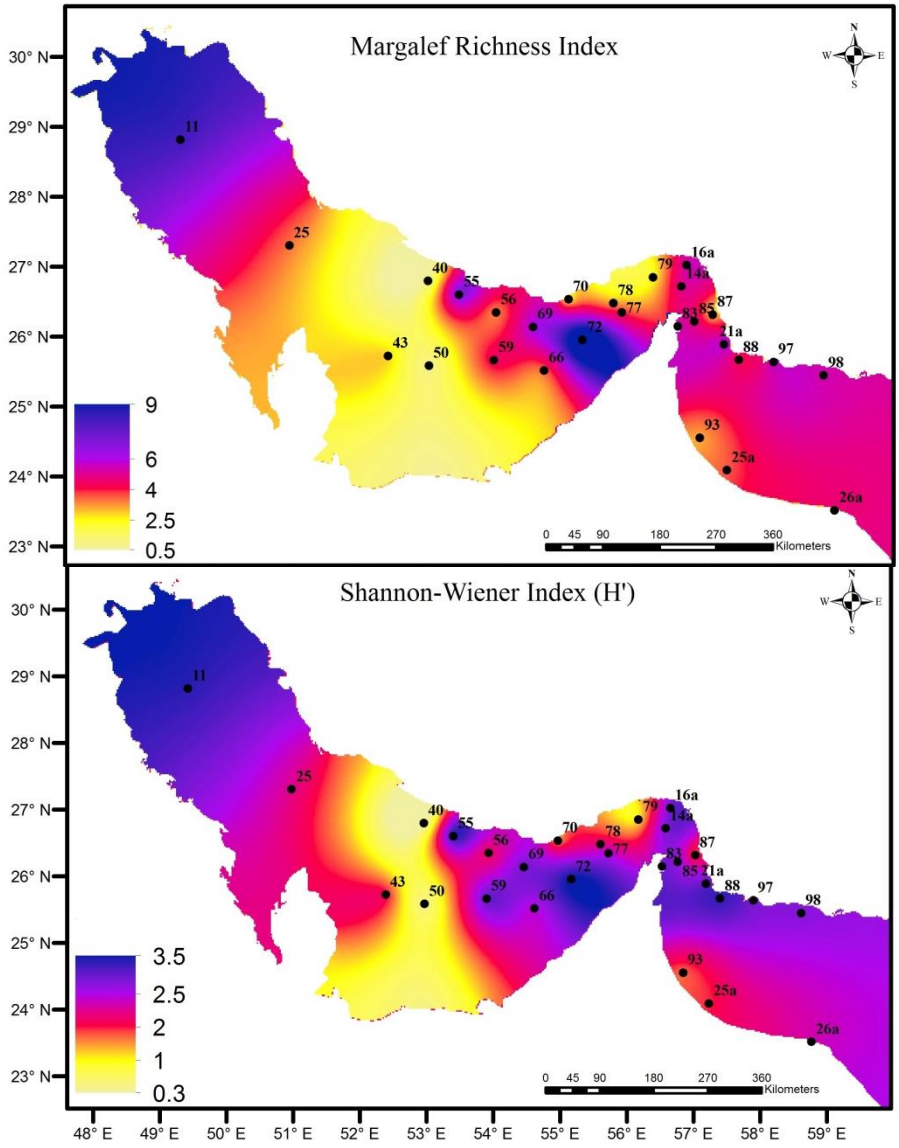

Figure 28: Spatial Distribution of Species Richness and Diversity Indices in the RSA, Winter 2006

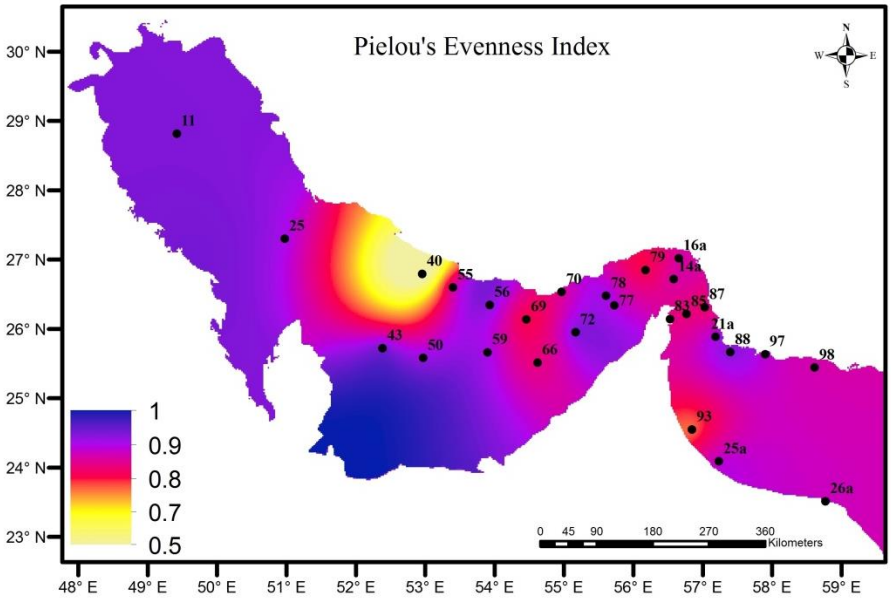

Figure 29: Spatial distribution of Species Pielous's Evenness Index in the RSA, Winter 2006

Based on abundance of each species, in the stations at 50% similarity, cluster analysis showed three groups. Group 1 comprised 3 stations (Stations 88, 55, 69) with highest abundance (Figure 30). One of these stations located in the Sea of Oman and two stations in Inner part of the RSA. Group II revealed the similarity of two stations in their abundance at 50% Bray-Curtis; these stations (14a and 16a) were located in the Strait of Hormuz. Group III comprised two stations (11 and 66) and the rest of the stations remained ungrouped.

Based on the presence and absence method in the 40% Bray-Curtis, stations were clustered in 4 groups in the RSA. Group I comprised 7 stations that are shown in Figure 31 by red box. Group II comprise 2 groups and group III and IV each comprised 2 stations. The cluster of the stations, based on fourth root and presence and absence, almost had the same pattern which are shown in Figure 32.

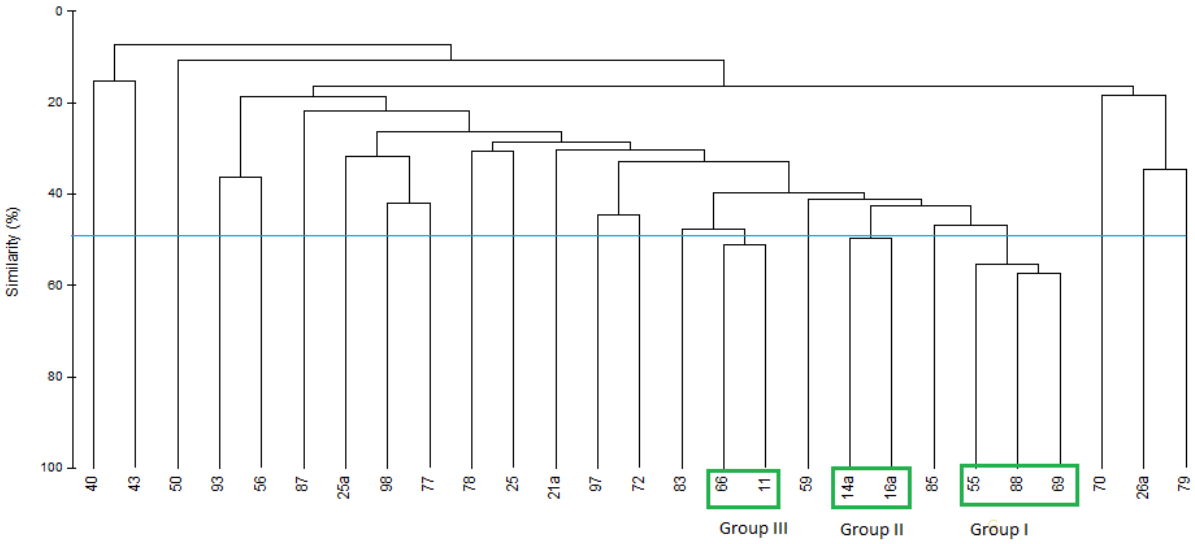

Figure 30: Cluster dendogram of 27 sampling stations based on dinocyst abundance using Bray-Curtis similarity coefficient and group average method. Grouping prepared at 50% similarity (Blue line).

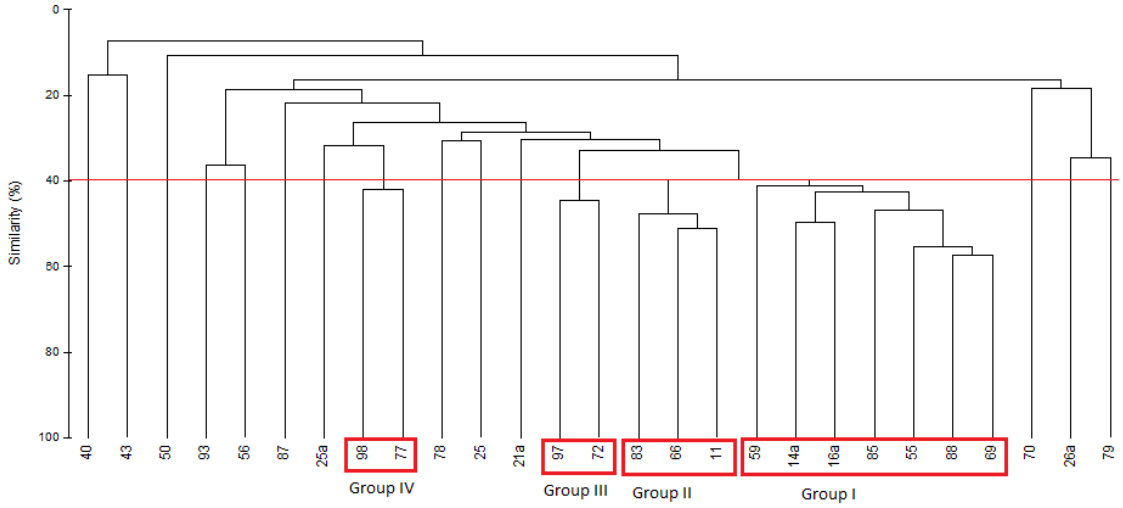

Figure 31: Cluster dendogram of 27 sampling stations based on presence and absence dinocyst using Bray-Curtis similarity coefficient and group average method. Grouping prepared at 40% similarity (Blue line).

3. 6. Potentially HABs Forming Cyst Species in the RSA

Roughly, 100 species of phytoplankton have potential to form Harmful Algal Blooms (HABs). Of these, 75% belong to dinoflagellate (D'Silva *et al.*, 2011). Some of the HABs forming Species produce resting cyst and some have the capability to fossilise. These provide

evidence of the global spreading or recession of HABs species. In recent years, knowledge of phytoplankton cysts has significantly increased, and utilized as a useful tool to aid phytoplankton monitoring in coastal areas.

Many researchers point to the important role of the cyst in the Harmful Algal Blooms (Dale, 1977; Angels *et al.*, 2012). Cysts play an important role in species dispersal, survival under unfavorable conditions, termination of blooms and initiation of future blooms (Anderson and Wall, 1978). Cysts may also be a source of toxin for benthic shellfish. Some benthic shellfish have very limited opportunity of feeding on planktonic cells. For these species, cysts of toxic species that accumulate on the surface of the sediments could be a toxin source.

Cysts in the sediments remain viable for long periods; from months to a century (Lundholm *et al.*, 2011). Therefore, the assessment of cysts in the sediments can clarify the occurrence of the species over time (Anderson, 1997, Persson, 2000).

Overall, cysts of 13 potential HABs species were recorded in the RSA, representing a potential hazard for outbreaks of harmful events associated with these species in the future.

The resting cyst of the harmful algal species that have been found in the RSA from Winter Cruise 2006 and their potential harmful effects are summarized in Table 8.

Table 8: Potential HABs or toxic phytoplankton species with resting stage in the RSA, Winter 2006

Species	Harmful Effect	References
Alexandrium minutum	PSP	Erard-Le Denn *et al.* (2000)
Alexandrium tamarense	PSP	Wyatt & Jenkinson (1997)
Alexandrium pseudogonyaulax	Neurotoxin	(Klein *et al.*, 2010)
Alexandrium affine	NeoSTX, STX, GTX	Nguyen-Ngoc (2004)
Gymnodinium catenatum	PSP	Bravo & Anderson (1994); Blackburn *et al.* (2001)
Protoceratium reticulatum	Yessotoxin	Faust (1997), Alvarez *et al.*, (2011)
Pyrodinium bahamense	PSP	Matsuoka *et al.*(1989)
Lingulodinium polyedra	Yessotoxin	Paz *et al.* (2004)
Chattonella sp	Ichthyotoxic	Haque & Onoue (2002)
Polykrikos hartmanni	Ichthyotoxic	Aktan and Keskin (2017)
Heterosigma akashiwo	Ichthyotoxic	Twiner & Trick (2000)
Scrippsiella trochoidea	Anoxia	Hallegraeff (2003)
Cochlodinium polykrikoides	Ichthyotoxic	Tang & Gobler (2009)

Relative abundance of potential Harmful Algal Bloom forming cysts species to non-bloom forming phytoplankton species varied in different stations (Figure 32). Potential HABs forming Species were distributed in all stations and more distributed along Strait of Hormuz, Oman and U.A.E coasts.

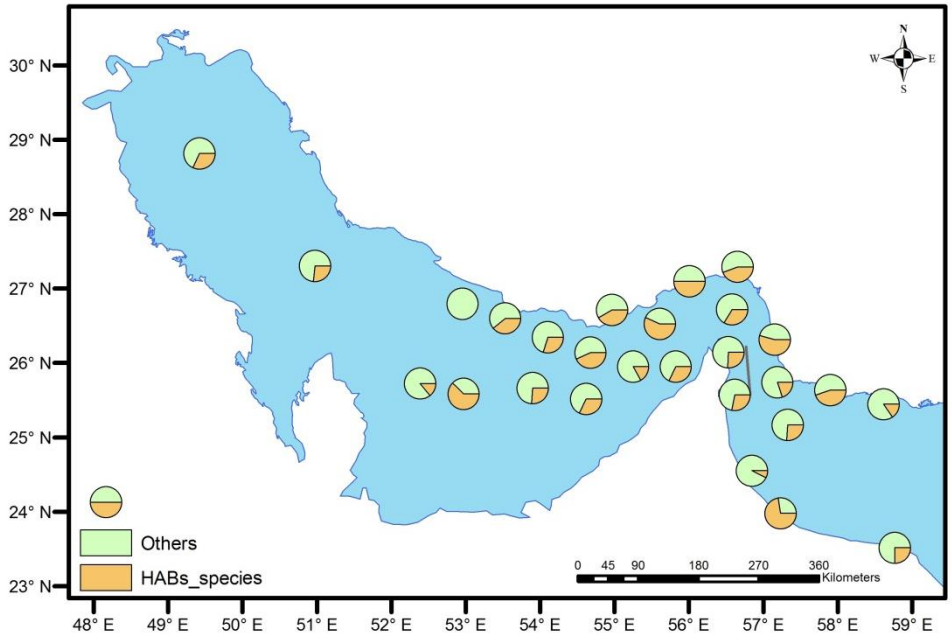

Figure 32: Relative abundance of potential HABs cyst species to other species in different stations along RSA, Winter 2006

The proportion of potential bloom forming cyst species was higher at some stations than the rest of the cyst species. The highest abundance with 72.7% was recorded in station 25a in the southern part of the Sea of Oman along the coast of Oman. Station 50 located at the southern part of the Inner RSA along UAE coast also had the second highest abundance with 62.5% compared to the rest of the species (Figure 33).

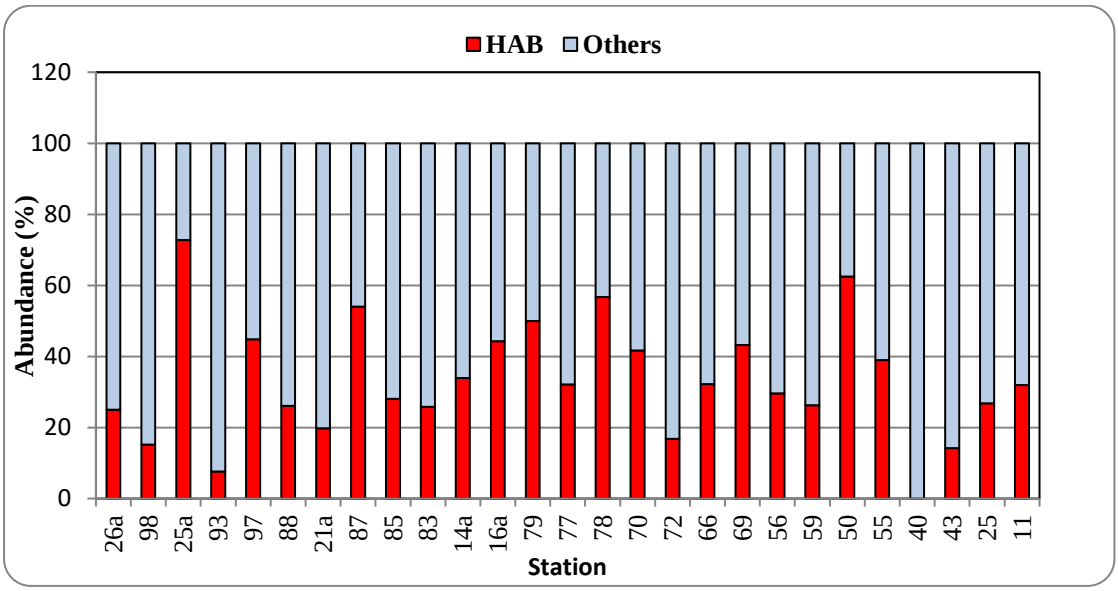

Figure 33: Composition of HABs forming cyst stage to others in different stations along RSA, Winter 2006

3.6.1 HABs Forming Species, Spatial Distribution in the RSA

Alexandrium minutum

One of the most important HAB genera in the coastal area is *Alexandrium* spp, in respect of its diversity, wide distribution and impact on marine ecosystems.

This species produces Paralytic Shellfish Poisoning (PSP), mainly gonyautoxin and also a potent ichthyotoxin that can affect human, fish, shellfish, and other mammals (Lush *et al.*, 2001). *A. minutum* produce colourless spherical cyst surrounded with a mucilaginous layer. Its motile stage is very similar to *Alexandrium angustitabulatum.*

The species can form bloom in the coastal area and discolour water to Reddish-brown. Harmful bloom of *A. minutum* has been reported from many coastal areas that have been associated with fish and shellfish mortality. These were from Egypt (Ismael and Khadr, 2003), Vietnam (Yoshida *et al.*, 2000) Thailand and Taiwan, Australia (Hallegreaff *et al.*, 1988) and dense bloom in the Mediterranean Sea, with 3.02×10^{3} *A. minutum* cysts cm^{-3} in the wet sediment (Bravo *et al.*, 2008).

In the RSA, *A. minutum* has been found in a few stations with very low cyst density (Figure 34). However, the abundance of this cyst is not proportional to the magnitude of the bloom (Ismael and Khdar, 2003). It is found that the distribution of the *A. minutum* cyst depends on sedimentation rate and continued erosion of the bottom sediment.

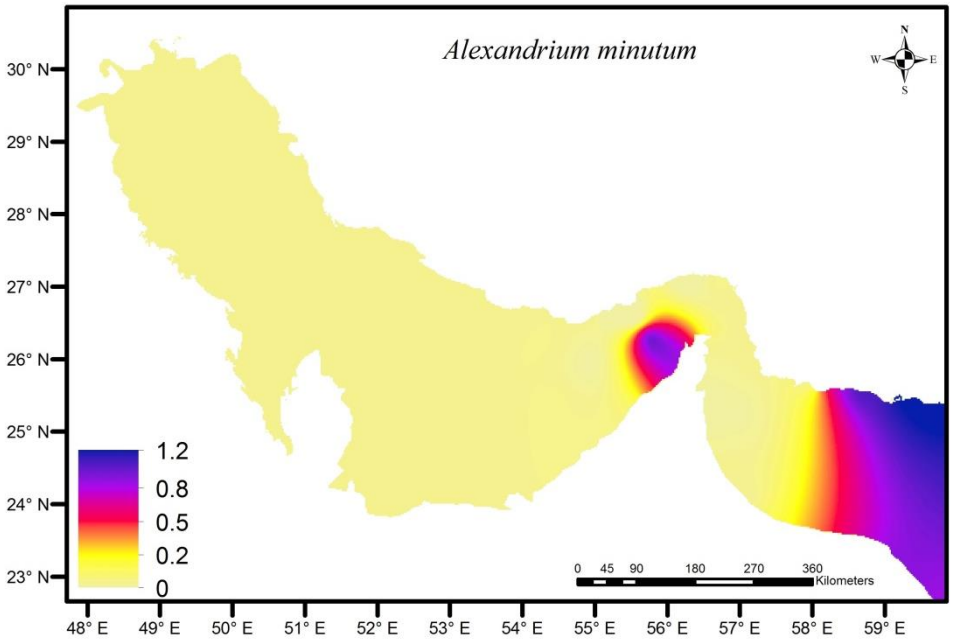

Figure 34: Spatial distribution of *A. minutum* cyst concentration (Cyst g^{-1} dws) in the RSA, Winter 2006

Alexandrium tamarense

This species has also the potential to produce PSP that can cause mortality in fish, shellfish and mammals. Some ribotype of *A. tamarense* are not toxic. The species produces an ellipsoidal cyst surrounded with mocoid layer in the RSA. *A. tamarense* cyst resembles the cyst of *A. catenella*. Cyst of *A. catenella* has also an ellipsoidal shape and is very hard to be distinguished from each other morphologically. Both species are bloom forming and PSP toxin producers. *A. tamarense* cyst has mainly a wide range of distribution in the shallow water depths (Natsuike *et al.* 2013). In the present study, the density of the cyst was not high and was only found in station 11 along Kuwait coast (Figure 35). Marret and Zonnevelld (2003) reported this species from southern Indian Ocean and the highest abundance is reported from China Sea. Bloom of this species in Australia caused the mortality of farmed rainbow trout and salmon (Hallegraeff 2003). There is no published data on Harmful bloom of this species in the RSA.

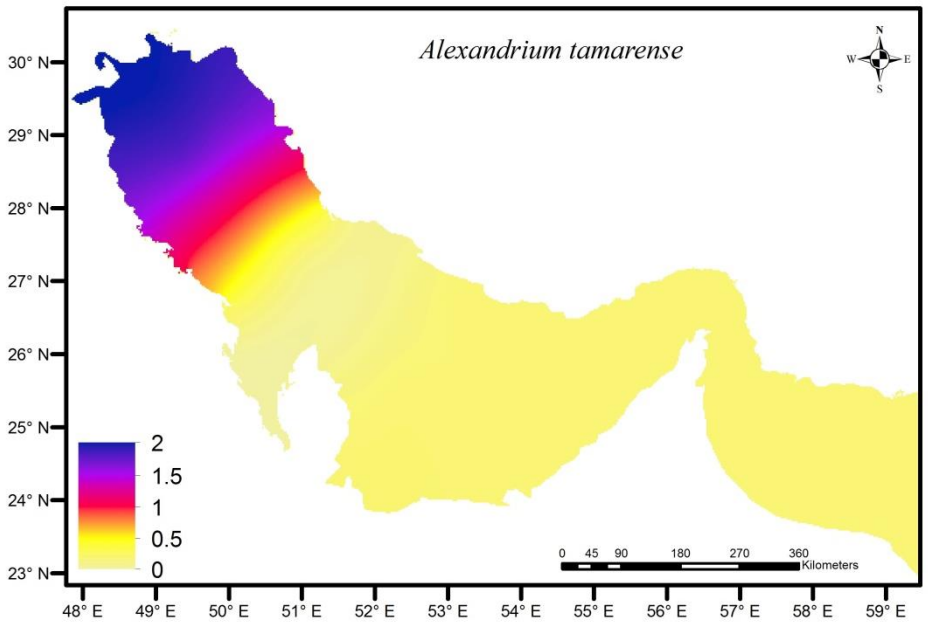

Figure 35: Spatial distribution of *A. tamarense* cyst concentration (Cyst g^{-1} dws) in the RSA, Winter 2006

Alexandrium pseudogonyaulax

This species of dinoflagellate produces Goniodomin A, a dangerous neurotoxin that has harmful effect on vertebrates (Kelien *et al.* 2010). The species produces a spherical paratabulated and smooth cyst wall. Cyst of this species is reported from many coastal areas; for example from Mediterranean Sea (Triki *et al.*, 2014), Italy (Montresor, 1995), Spain (Alfacs Bay) (Bravo *et al.*, 2006) with no reporting of species bloom in this area. However, bloom of the species has been recorded from Alfacs Bay (Ebro Delta) in 2003 and 2004 (Bravo *et al.*, 2006) and Norwegian Sea (Throndsen *et al.*, 2007) with high cyst concentration.

In the RSA, the cyst of this species was distributed in several stations (Figure 36) along Iran, Kuwait and Oman coasts, but in low density. This species was not previously reported from coastal area of Strait of Hormuz and the Sea of Oman and this is the first report of the cyst from recent sediments of RSA. Tiriki *et al.*, (2014) documented that the cyst concentration of this cyst type has positively correlated with the silt in the sediment and water content. In the RSA, the cyst was found more in the muddy sediments.

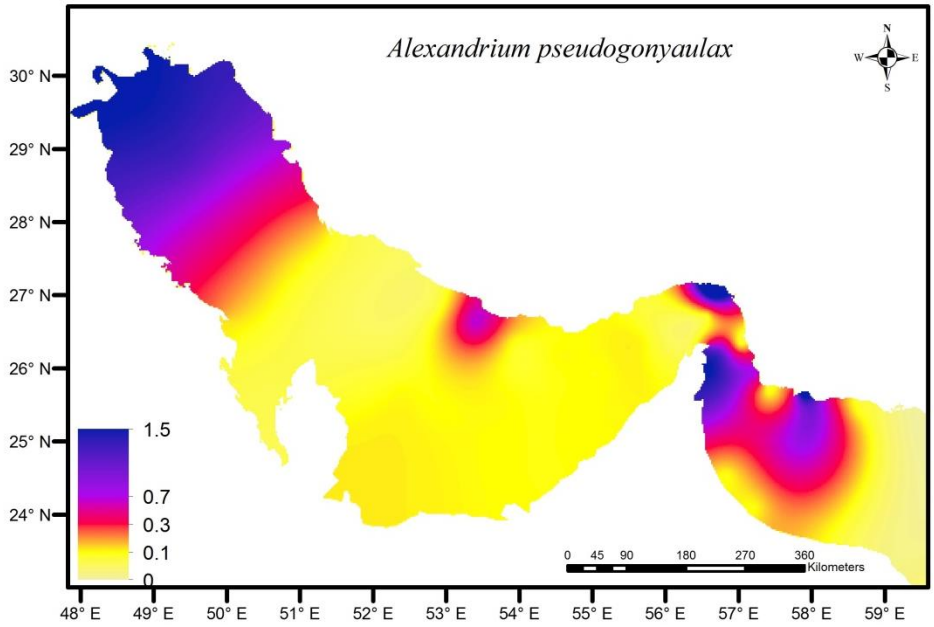

Figure 36: Spatial distribution of *A. pseudogonyaulax* cyst concentration (Cyst g^{-1} dws) in the RSA, Winter 2006

Alexandrium affine

This species is potentially a bloom forming species in the genus *Alexandrium*. The species usually blooms with other species such as *Gymnodinium catenatum,* Cochlodinium sp., and *Pheopolykrikos hartmannii* (Band-Schmidt *et al.*, 2003). The population of *A. affine* is in two forms; namely, the toxic form (Nguyen-Ngoc, 2004) and non-toxic form (Band-Schmidt *et al.*, 2003). Cyst of *A. affine* is spherical and surrounded with mucouid layer.

In the RSA, the density of the cyst was not high, but found in 12 stations along RSA. The highest mean density was observed in station 98 with an average of 2.6 cyst g^{-1}dws along Iranian coast in the northern part of the Sea of Oman (Figure 37). Highest density of the cyst in the sediment was reported in spring and summer, which coincides with the presence of the high density of motile cell in water column (Morquecho and Lechuga-Devéze 2004). It was found that among the cyst species of *Alexandrium,* the highest percentage belonged to *A. affine* cyst in Iranian coast of the Sea of Oman (Attaran-Fariman, 2016). In that study, the cyst was reported in 26m to 28m depth from eastern part of the Sea of Oman and almost same location that sediment collected in the ROPME Cruise in Winter 2006. However, in the RSA, the cyst showed high concentration in the depth of 50m.

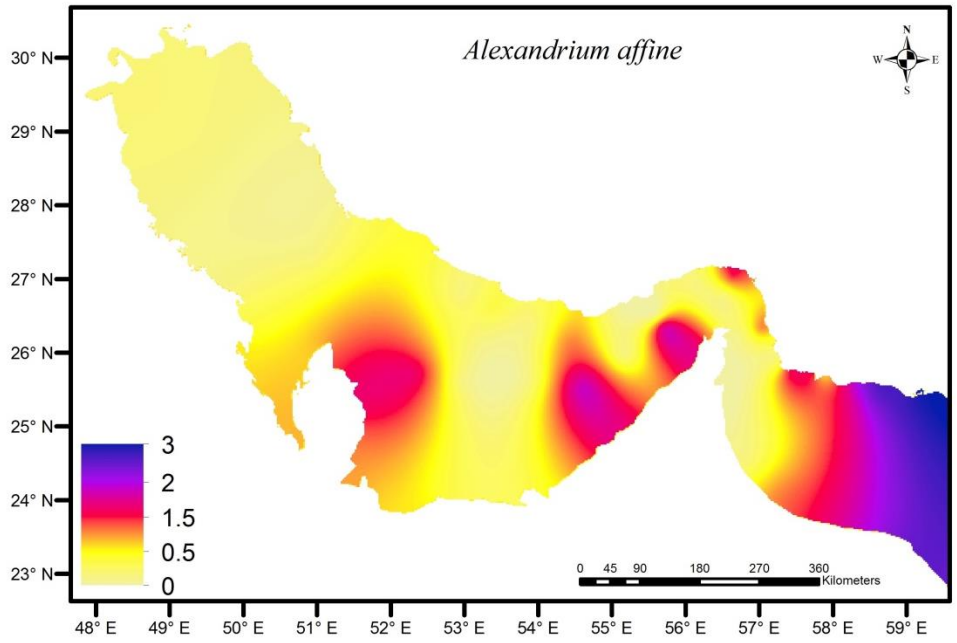

Figure 37: Spatial distribution of *A. affine* cyst concentration (Cyst g^{-1} dws) in the RSA, Winter 2006

Gymnodinium catenatum

There are 4 species in the Genus *Gymnodinium* that produce microreticulate resting cyst; namely, *G. nolleri, G. catenatom, G. trapeziforme,* and *G. microreticulatum*. Among these, only *G. catenatum* has the potential to form massive blooms and produce PSP. Additionally, their cells are capable of forming long chains. The toxin profile of this species is varied in different geographical regions (Park *et al.* 2006). The toxin can accumulate in the shellfish and marine mammals (Hallegraeff *et al.*, 1988; 1995) and if ingested by humans, the poisonous shellfish can cause neurological and gastro-intestinal problem and frequently results in PSP symptoms and death by respiratory paralysis (Faust and Gulledge, 2002).

The cyst of this species has been introduced to some areas via ballast water and caused major economical loss. Japan, Korea, Spain, and Portugal have been identified as the main origin of these cysts in the ballast tanks. Sediment investigation for the cyst has demonstrated that the cyst did not exist in Australia before 1973 and toxic blooms of *G. catenatum* appeared after this year in Australian water for the first time ((McMinn *et al.* 1997; Hallegraeff, 2003).

In the RSA, the cyst density average varied between 0.3cyst/ g dws in station 83 (located in the Strait of Hormuz) to 9.9 cyst/g dws in station 88 (located in the Iranian coast of the Inner RSA) (Figure 38). These cysts often comprise low density of the total cyst flora (Hallegraeff *et al.*, 2012) and have capability to fossilize. Hallegraeff *et al.* (2012) documented that in the tropical region such as Mexico, the high proportion of blooms have been associated with an increase in nutrients.

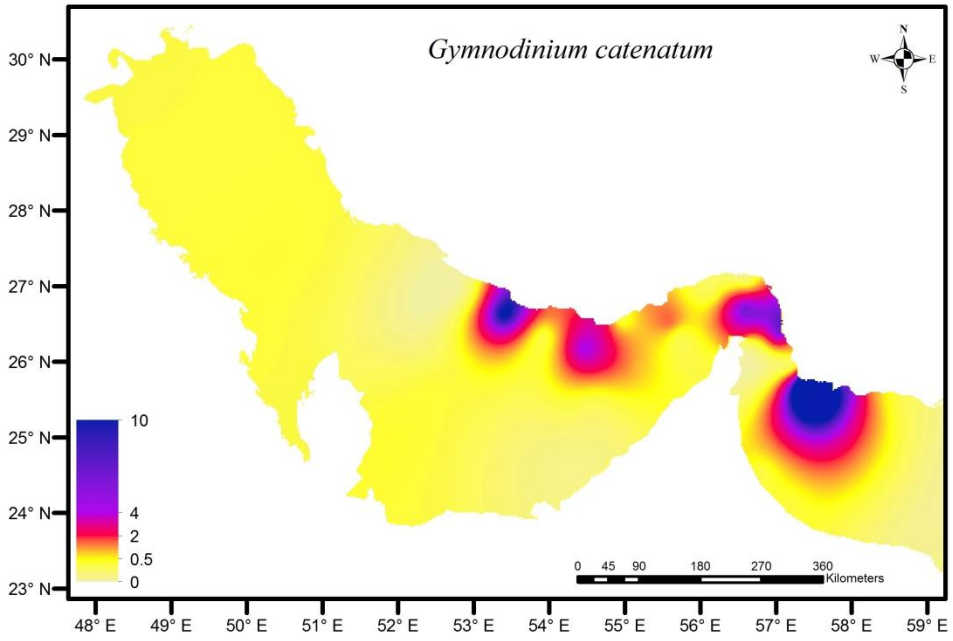

Figure 38: Spatial distribution of *G. catenatum* cyst concentration (Cyst g^{-1} dws) a potential bloom forming Species in the RSA, Winter 2006

Protoceratium reticulatum

The species is potentially a bloom forming and toxin producer in coastal areas. Cysts in sediment act as seeds for initiation of the bloom through excystment. In Chile, the bloom was initiated offshore by motile cells and germinated cysts in summer 2007 (Alvarez *et al.*, 2011). Large mortality of black and white mussels in the coast of South Africa was related to *P. reticulatum* (Joyce 2004). Some strain of this species produce yessotoxin that can affect mollusk and human health (Hallegraeff, 2003; Alvarez *et al.*, 2011). In the Inner part of the RSA, in Qatari water, *Protoceratium* was reported as a source of yessotoxin (Al Muftah *et al.*, 2016).

The cyst of this species is spherical with capitate spines and has been previously reported from Iranian coastal area of the Sea of Oman (Attaran-Fariman 2016). In this study, the cyst was recorded in several stations along RSA (Figure 39) and showed maximum abundance in station 88 with the density of 13.5 cyst/gdw in northern part of the Sea of Oman along Iranian coast.

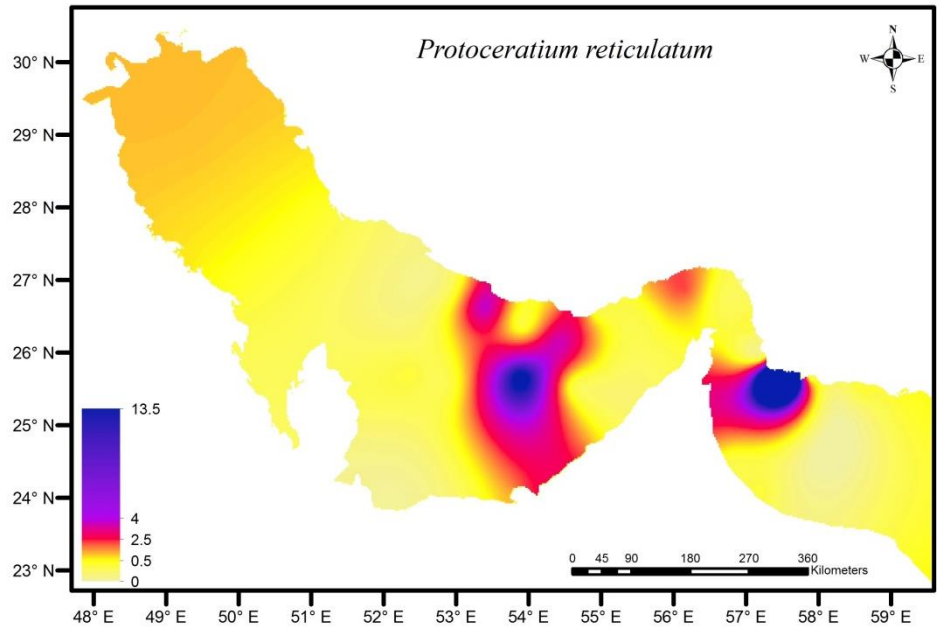

Figure 39: Spatial distribution of *P. reticulatum* cyst concentration (Cyst g^{-1} dws) a potential bloom forming Species in the RSA,

Pyrodinium bahamense

The species is a bloom forming and a typical warm water species, which is distributed in the tropical and subtropical regions from Indian Ocean to Pacific. The first harmful bloom of this species was in Papupa New Guinea in 1972, and after that toxin spread in other tropical regions such as the Philippines and RSA (Bradford and Wall 1984; Hallegraeff 2003).

Pyrodinium bahamense produces PSP that can affect shellfish, mussels, oyster, and fish. Its toxin caused human mortalities after the consumption of contaminated shellfish in 1987 in Guatemala (Hallegraeff 2003). Similar incidents are still occurring; for example, in

2007, in localities around the Philippine Islands, where the geographical distribution of PSP incidents is widespread.

The resting cyst is spherical and distally open process and have important role in the initiation of blooms (Usup *et al.* 2012), and at the end a bloom encystment happens (Villanoy *et al.*, 1996). Blooms form in the shallow and semi-enclosed area when cysts re-suspend by turbulence (Usup *et al.* 2012).

In the RSA, maximum density of the cysts were noticed in station 66, located in the Inner RSA along U.A.E coastal area (Figure 40). The cyst has also been reported from Strait of Hormuz with highest abundance in the summer (Attaran-Fariman 2016). The cysts were found to be abundant along the Inner RSA in the study of Bradford and Wall (1984). *P.bahamense* includes two varieties; namely, *bahamense* and *compressum* (Steidinger *et al.* 1980). Identification of the two varieties is supported by morphological variations, different geographical distributions, and production of paralytic shellfish toxins (PSTs) of the motile stage (Morquecho *et al.*, 2014). Meftah *et al.* (2016) documented in Kuwaiti water PST in *P. bahamense* var. *compressum* is similar to that in Palau and Malaysian isolates.

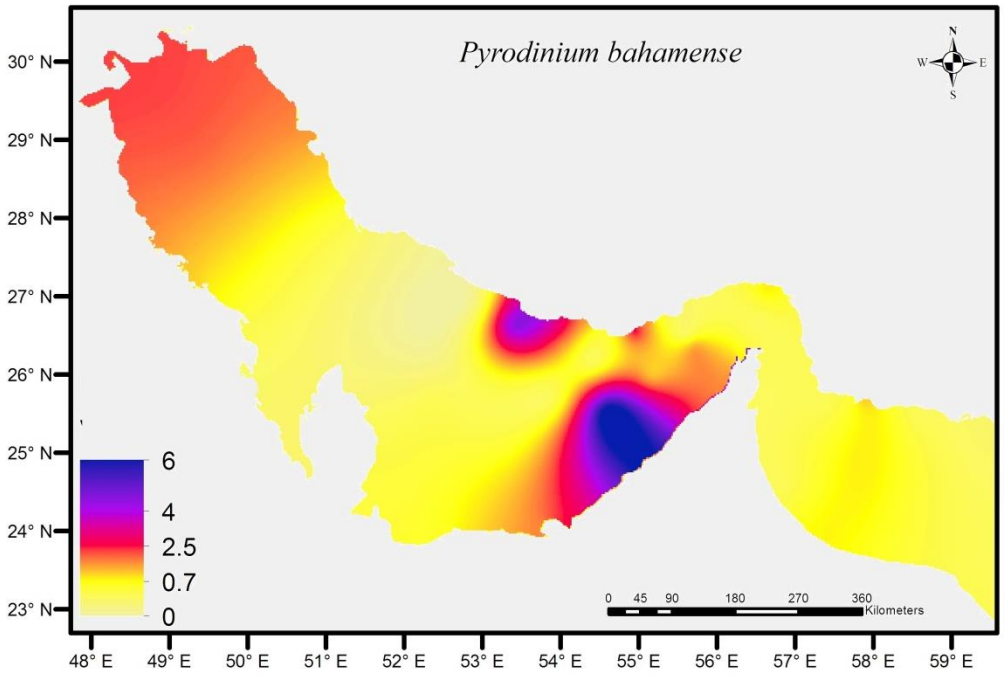

Figure 40: Spatial distribution of *P. bahamense* cyst concentration (Cyst g^{-1} dws) a potential bloom forming Species in the RSA

Lingulodinium polyedrum

This species was the most common cyst species among HABs forming Species in the RSA and found in most stations. *L. polyedrum* cyst was widely distributed from warm temperate to the subtropical. The species has the potential to form harmful blooms and produces yessotoxin (YTX) (Paz *et al.* 2004). Muftah *et al.*, (2016) found a species from Kuwaiti water in the RSA that produced yessotoxin (YTX). The bloom has been associated with the fish and shellfish mortality in different regions such as coast of California (Moorthi *et al.* 2006) and North Pacific coast of Costa Rica (Morales-Ramírez *et al.*, 2002). The toxic syndrome of YTX is not well defined in humans.

Cyst of *L. polyedrum* has been previously reported from northern part of the Sea of Oman in Iranian coastal sediments (Attaran-Fariman 2012; 2016). In the Winter 2006 along RSA, this species was common and found in several stations and comprises the highest abundance among HABs forming Species. The occurrence of the species is usually related to the eutrophic condition of the water column (Dale and Fjellså, 1994). The bloom of the species is generally documented during warm water condition and stratified water column (Lewis and Hallet, 1997).

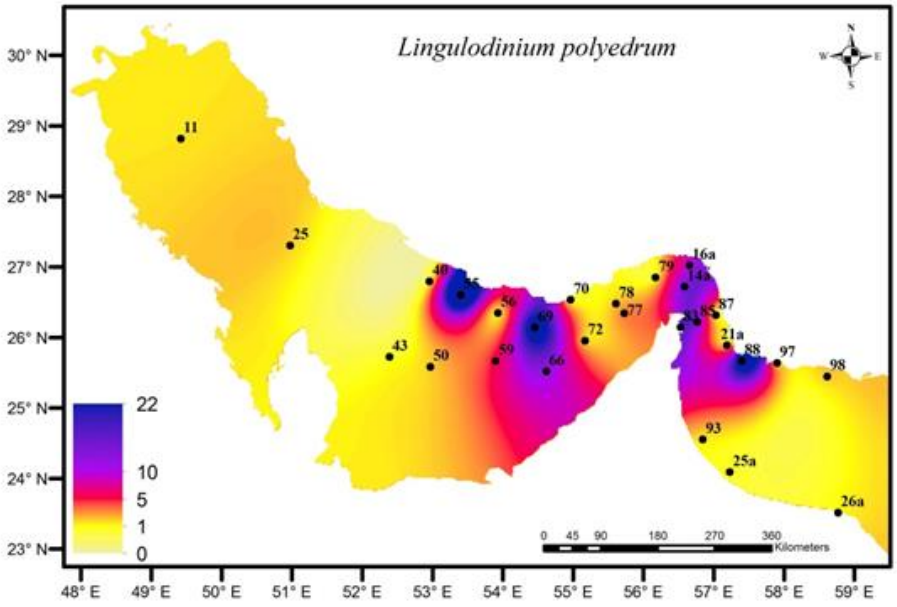

Figure 41: Spatial distribution of *L. polyedrum* cyst concentration (Cyst g^{-1} dws) a potential bloom forming Species in the RSA,

Scrippsiella trochoidea

S. trochoidea is potentially a bloom forming Species. The species is not toxic but can cause mortality in shell and shellfish by depleting oxygen levels (Hallegraeff and Bolch, 1992*). S. trochoidea* is a cosmopolitan dinoflagellate in coastal waters and widely distributed in the coastal area (Sprangers et al., 2004) and in the northern part of the Sea of Oman (Attaran-Fariman, 2016). The species tolerates a wide range of salinity and temperature (Kim and Han, 2000). It has a high efficiency in the production of cysts, which can be an explanation for its success in the neritic environment where cyst act as seed for vegetative population (Wang *et al.*, 2004; Wang *et al.* 2007).

Harmful bloom of this species is reported from many coastal regions; South Australia in 1983 (Hallegraeff, 2003); South China Sea almost every year since its first occurrence in 1998 (Wang *et al.*, 2007). It has been documented that high cyst concentration is followed by high concentration of vegetative cells (Olli and Anderson, 2002; Joyce and Pitcher, 2004). Therefore, cyst formation has an important role in bloom termination.

S. trochoidea cyst in the study of Attaran-Fariman (2007) comprised the highest percentage of cyst flora in the RSA, along the northern part of the Sea of Oman in station 88, where depth of sediment sampling varied from 1m to 6m. Al-Hashmi *et al.* (2015) documented the *S. trochoidea* as HAB forming Species in the Sea of Oman and its presence in the water column all the year. This shows its capability to bloom in the RSA under favorable conditions such as proper light intensities and low turbulence (Al-Hashmi *et al.* 2015). In Winter 2006, in the RSA, among HAB forming Species, *S. trochoidea* comprised 10% of cyst flora and was recorded in the sediments of 15 stations; with highest mean abundance in station 85 along the northern part of the Sea of Oman (Figure 42).

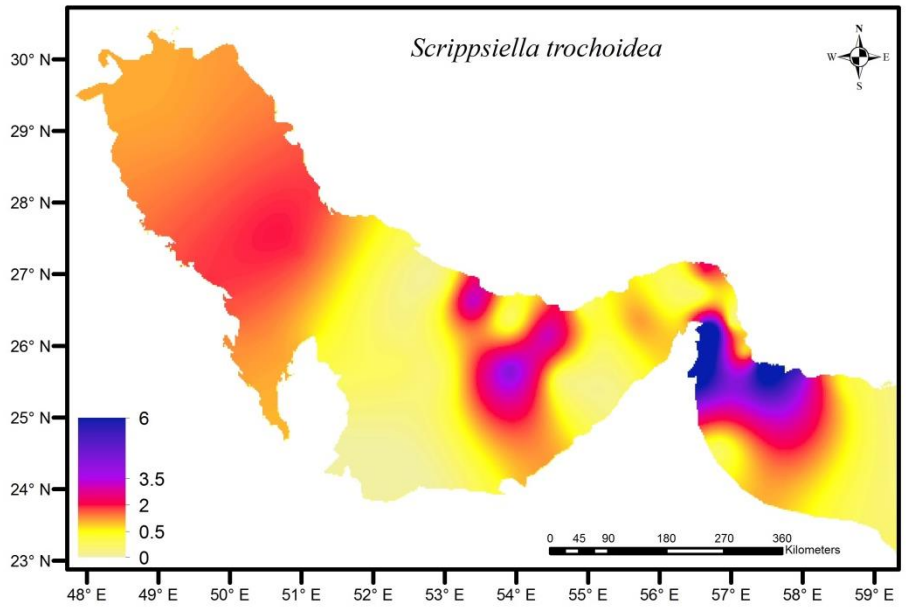

Figure 42: Spatial distribution of *S. trochoidea* a potential bloom forming Species in the RSA

Cochlodinium polykrikoides

C. polykrikoides is a potentially harmful bloom forming dinoflagellate, which is widely distributed in the coastal areas around the world (Whyte *et al.*, 2001; Azanza *et al.* 2008). Harmful blooms of this species has been reported from many regions, such as in Shinnecock Bay, USA during 2002-2006 (Gobler *et al.* 2006). The species produces ichthyotoxic substances that cause marine organism mortality (Gobler *et al.* 2012). It has been reported to cause metamorphism in the larvae of Pacific oyster during species bloom (Matsuyama *et al.*, 1997). The distribution of *C. polykrikoides* in Asia has been increasing. It was reported from Japan in 1978 for the first time (Matsuoka and Iwataki 2004). It has then been observed in Korea in 1985 (Kim 2005), in Malaysia and the Phillipines in 2005 (Relox and Bajarias 2003; Anton *et al.* 2008), the Sea of Oman and the Inner RSA in 2010 (Attaran-Fariman 2010; Matsuoka *et al.* 2010).

In the RSA, harmful bloom of this species started in 2008-2009 resulting in massive fish mortality during 2008-2009 (Matsuoka *et al.* 2010). Its bloom has been documented in the northern and southern part of the Sea of Oman along Iranian and Omani coastal areas (Attaran-Fariman 2010; Al-Hashmi *et al.* 2015).

The presence of C. *polykrikoides* cyst has been noticed from coastal sediment of Chabahar Bay and Gwater Bay for the first time in 2013 (Attaran-Fariman *et al.*, 2013;

Attaran-Fariman and Raiisi, 2015). These Bays are located in the northern part of the Sea of Oman and southwest coast of Iran. The cyst subsequently reported from several stations along the Sea of Oman and Strait of Hormuz (Attaran-Farimen, 2016).

The role of the cyst in the sediment, as seed banks for initiation of bloom, has been documented by some studies (Hattenrath-Lehmann 2015). In Winter 2006, in the RSA, cyst of *C. polykrikoides was* found to have relatively high abundance among HABs forming Species with a maximum density in station 66, located in the coastal area of U.A.E and also in station 55 along Inner part of the RSA (Figure 43).

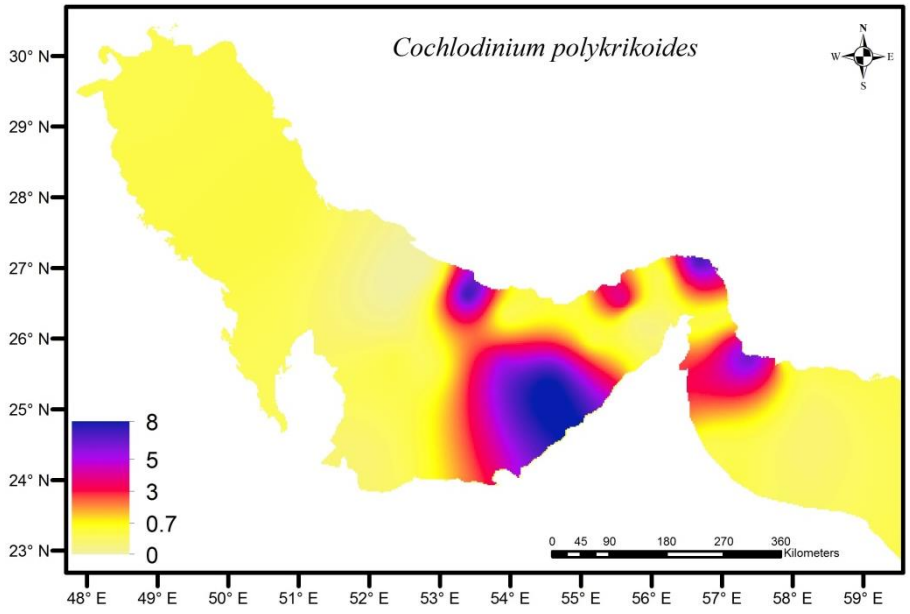

Figure 43: Spatial distribution of *C. polykrikoides* cyst concentration (Cyst g^{-1} dws) a potential HABs Species in the RSA, Winter 2006

Polykrikos hartmannii

P. hartmanii is a potentially harmful and ichthyotoxic species that produces resting cyst. The species is widely distributed in temperate and tropical waters (Aktan and Keskin, 2017). The species forms harmful bloom in the coastal area; in Korea in 1982 (Kim *et al.* 1990); Florida, USA in 2004 (Badylak and Phlips 2004); USA (New York) in 2008 (Tang *et al.* 2013) and serious ichthyotoxicity to juvenile Sheepshead minnows (*Cyprinodon variegates*)(Tang *et al.* 2013).

In the RSA, the species density was not high among HABs forming Species. The cyst showed highest density in station 55 located in the Iranian coast of the Inner RSA (Figure 19).

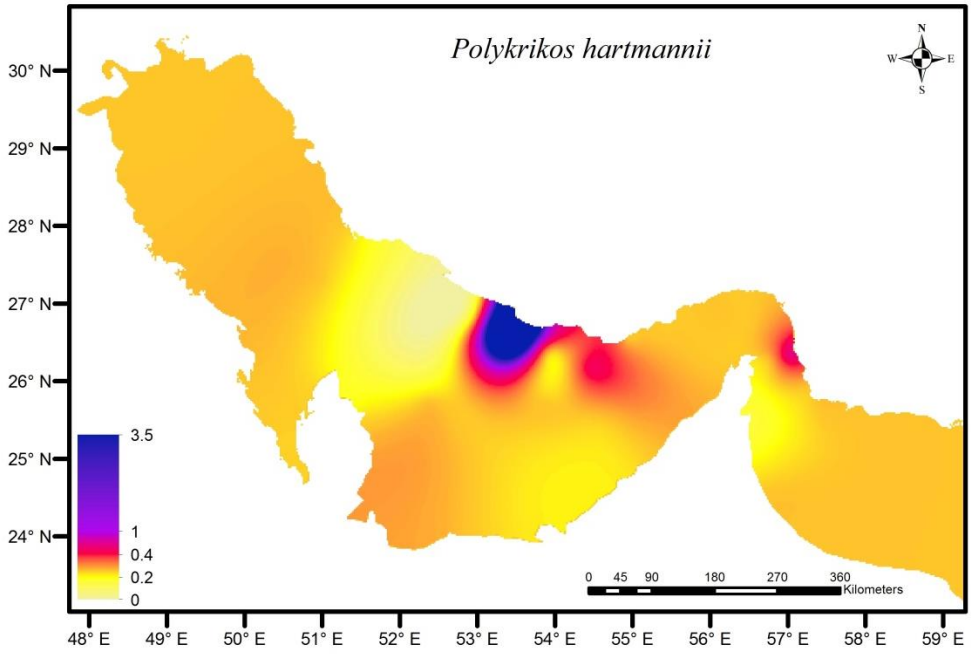

Figure 44: Spatial distribution of *P. hartmannii* potential HABs forming Species in the RSA, Winter 2006

Heterosigma akashiwo

H. akashiwo is potentially a noxious bloom forming species belonging to raphidophycae. The species blooms damage many fish farms in the coastal area (Rensel *et al.*, 2010). Massive bloom of the species in New Zealand caused mortality of cage Chinook salmon in June 2000 and loss of NZ$12 million dollars (Hallegraeff, 2003).

In the RSA sediment samples, *H. akashiowo* was found in low density only in a few stations (Figure 45). Identification of this cyst in the field sediment is difficult because of its small size and attachment to the sediment particle (Han *et al.* 2002). However, redescription of the species by Kim *et al.* (2015) proposed some features that helped the identification of cyst from environmental sample. There is no report on bloom of this species in the RSA.

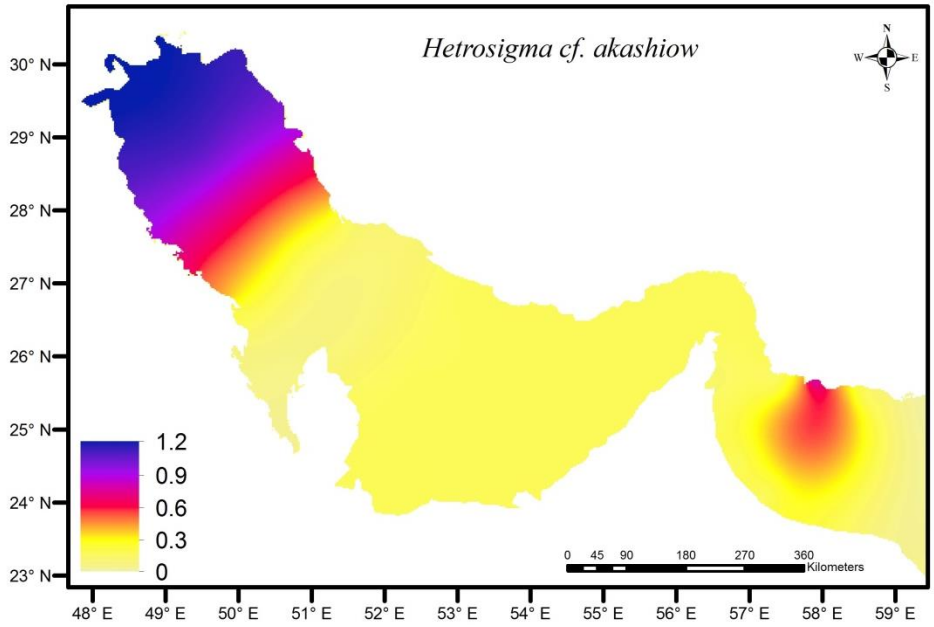

Figure 45: Spatial distribution of *Heterosigma akashiwo* a potential HABs forming Species in the RSA, Winter 2006

***Chattonella* sp**

Among chattonella species, some are found to form harmful blooms. *Chattonella marine* in the genus is noxious. This species caused problem for yellowtail aquaculture in Japan in 1972 and a loss of US$0.5 million (Hallegraeff *et al.*, 1998).

In the RSA, this cyst was found only in 3 stations along UAE and the coastal area of Oman (Figure 46).

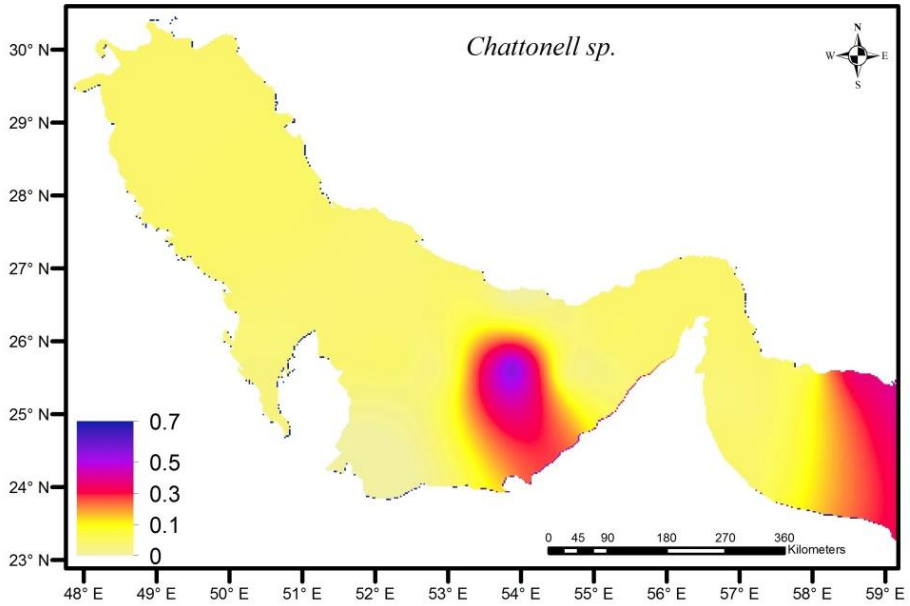

Figure 46: Spatial distribution of *Chattonella* sp. a potential HABs forming Species in the RSA, Winter 2006

3.7. Relationship between Dinocysts and Environmental Variables

Canonical Correspondence Analysis (CCA) was carried out on the abundances of dinocysts. The abundant dinocyst species were used as data (n=29) in multivariate analysis. All the species used in the CCA analysis had an abundance of >1%, except for the *Polykrikoides hartmanii* species that had a 0. 5% abundance. This was considered in the analysis, because it is a warm water species, which has a potential for producing harmful blooms. In the CCA, some sites were excluded, because the environmental data were not available. There was no data on the water quality of sites 11 and 43, and also in site 43, organic materials and metals were not measured. The quality parameter of bottom waters (CTD Data) that were used in the CCA are as following: Nitrate-N, Phosphate-P, Silicate (Si), Ammonia-N, Dissolved Oxygen (DO), Temprature (Tem), pH, Salinity (Sal), Turbidity (Tur), Depth, and Condectivity (Ec).

CCA results from dinocyst abundance in the RSA (Figures 47 and 48) revealed the relationship of 29 species of dinocyst density with 15 environmental variables in different stations. The position of the species and sample sites on the CCA biplot diagram show their species composition and their connection to the environmental factors. The length of environmental arrow and their ordination display their relative importance and approximate

correlation to the axis (Figure 48). Based on Forward Selection (Table 9A) and Monte Carlo test of the 15 environmental variables, ammonia and phosphate were statistically significant (p-value ≤ 0.05) The results of CCA showed that 40.6 % of the total inertia (3.019) in the species data was explained by environmental variables (Table 9B).

Table 9: (A) Forward selection analysis (B) Results of DCA analysis for the first four axes

(A)

Variable	LambdaA	P_{value}	Variable%
Ammonia	0/33	0/002	33
Phosphate	0/21	0/014	21
Turbidity(Turb)	0/17	0/168	17
Silicate	0/18	0/07	18
pH	0/16	0/102	16
Nitrate	0/13	0/194	13
O2sat	0/11	0/402	11
Conductivity (Cond)	0/17	0/06	17
Nitrite	0/12	0/308	12
O2ppm	0/1	0/502	10
Salinity(Sal)	0/09	0/526	9
Temperature(temp)	0/17	0/048	17
SigmaT	0/15	0/118	15
Depth	0/1	0/288	10
Chlorophyll (Chl)	0/08	0/472	8

(B)

Axes	1	2	3	4	Total Inertia
Eigenvalues	0.448	0.325	0.233	0.22	3.019
Species-environment correlations	0.921	0.979	0.935	0.978	
Cumulative percentage variance of species data	14.8	25.6	33.3	40.6	
Sum of all canonical eigenvalues					2.093

The inter-set correlation of water quality variables with the CCA axes display that ammonia was strongly related to the axis 1 and saturated oxygen to the axis 2. The

parameters of phosphate, ammonia, depth, Cond, Sal, pH and SigmaT had the highest correlation with the first CCA index.

The parameters of nitrate, temperature, O2sat and O2ppm have the highest correlation with the second axis of the CCA (Table 10). The species are classified into four groups based on their density correlation with the water quality parameters of the bottom sediment. The first group in the first quarter; the *Scrippsiella trochoidea (Stro), Diplopsalis lenticula (Dile), Gonyaulax membranacea (Gome)*, and *Alexandrium affins (Alaf*) species have a positive correlation with ammonia, temperature and turbidity. Moreover, these species have a negative correlation with nitrate, nitrite and Chl (Figure 47).

Table 10: Interest correlations between first two species axes and environmental variables in Canonical Correspondence Analysis (CCA) in the surface sediment of RSA, Winter 2006

Variables	Axis 1	Axis 2
Nitrate	0.0446	*-0.4318
Nitrite	0.0493	-0.0774
Silicate	-0.1336	-0.0523
Phosphate	*0.3940	-0.3039
Ammonia	*0.7804	0.2402
Depth	*-0.3694	-0.0801
Temperature	0.2083	*0.2105
Conductivity	*-0.3875	0.2994
Salinity	*-0.4067	0.2334
O2 sat%	-0.1094	*0.4830
O2ppm	-0.1549	*0.3295
pH	*-0.3355	0.0935
Chlorophyll	0.0359	-0.2989
Turbidity	0.0722	0.2599
SigmaT	*-0.4127	0.1769

Parameter with the * shows higher correlation

The second group in the second quarter of the left-hand side of the *Polykrikos hartmannii (Poha), C. polykrikoides (Copo), Protoperidinium conicoides (Prcd), Pyrodinium bahamense (Pyba), Pyrophacus steinii (Pyst), Scrippsiella irregularis (Scir), Lingulodinium polyedrum (Lipo*), *Spiniferites mirabilis (Spmi)* and *Gymnodinium catenatum (Gyca)* species have positive correlation with O_2%sat, O_2ppm, Conductivity (cond), Salinity (sal), SigmaT and pH parameters. These species have a negative correlation with nitrate, nitrite, chlorophyll and phosphate. *Calciodinelum opresom* (Caop) has the highest correlation with the negative side of the first axis.

10 species were placed in the third quarter. *The Protoperidinium compressum (prco), Protoperidinium cf. Punctulatum (prpu)* and silica species are positively correlated. Species *Protoperidinium claudicans (Prcl), Protoceratium reticulatum (Prre), Protopredinium (Psp7), Protoperidinium conicum (Prcm), Protoperidinium denticulatum (Prde), Spiniferites ramosus (Spra), Protoperidinium latissimum (Prla),* and *Protopredinium* Psp1 have a positive correlation with the negative axis of the second axis with chlorophyll and nitrate parameters. In addition, they correlate with the silicate parameters and depth. The fourth group in the fourth quarter, *Protoperidinium avellana* (Prav), has a positive correlation with nitrite, phosphate, chlorophyll, and Nitrate. *Protoperidinium shanghaiense A (PrsA)* has the highest correlation among the species with the positive side of the first axis, so it has a strong correlation with the amount of ammonia.

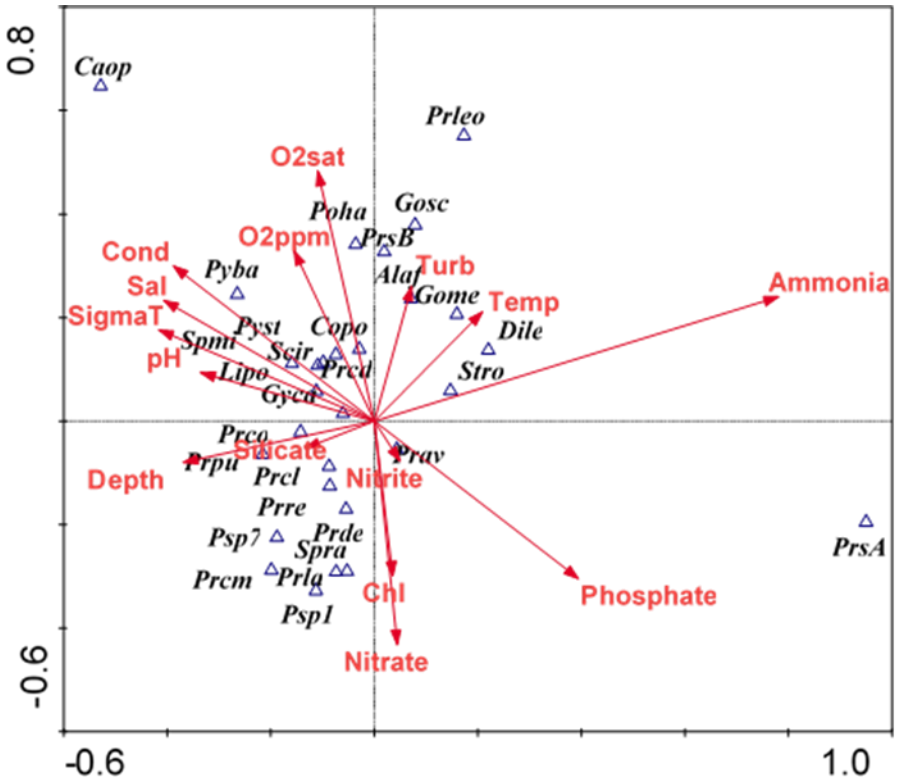

Figure 47: Ordination Diagram for the first two principal axes in the CCA analysis for dinocyst abundance (>1% abundance) of the surface sediment associated with water quality variables at RSA, Winter 2006

The Ammonia parameter correlates negatively with the depth, conductivity and salinity. It has a positive correlation with temperature and turbidity. Salinity with SigmaT has a strong positive correlation with salinity, chlorophyll, ppm O_2 and O_2 sat. Depth correlates positively with SigmaT, salinity and conductivity (Figure 48).

As shown in Figure 49, high species diversity is observed at stations positioned in the second and third quarters of the chart. The presence of species alongside the stations shows the presence of species at the station.

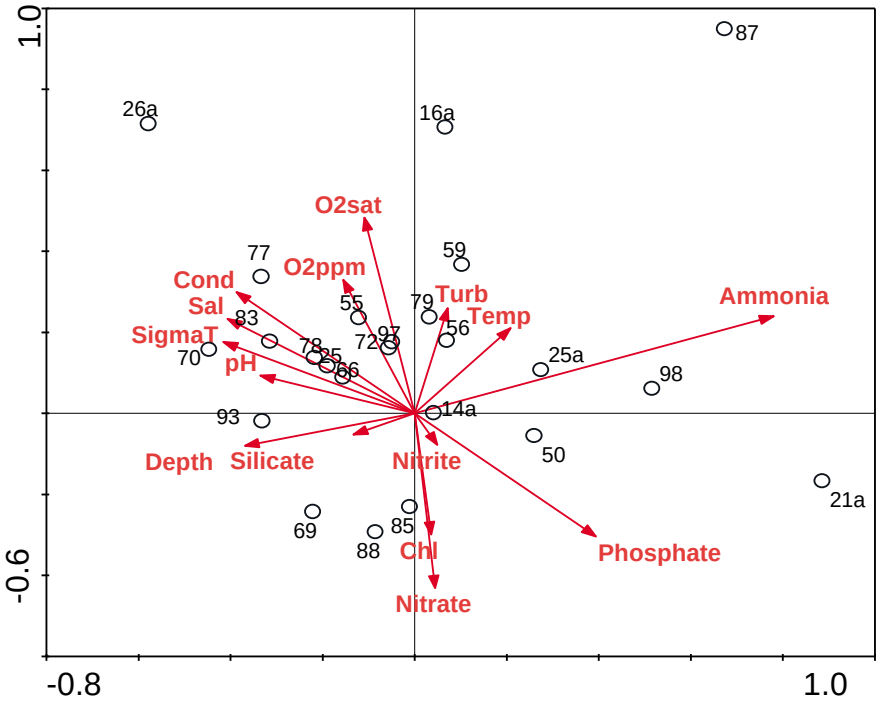

Figure 48: Ordination Diagram for the first two principal axes in the CCA analysis based on sites and with water quality variables at RSA, Winter 2006

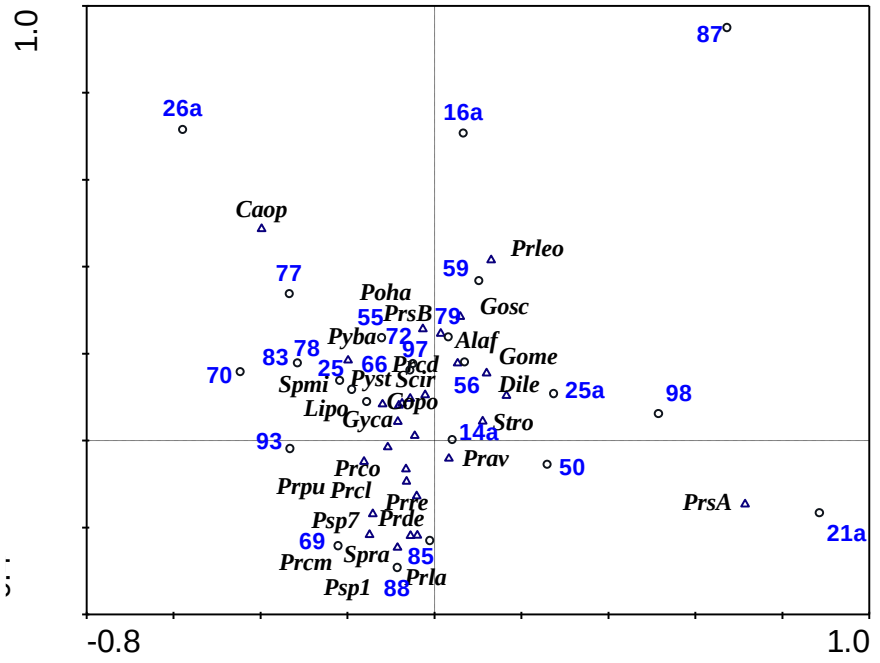

Figure 49: CCA results of RSA sites showing ordination of species and sampling sites. The species abbreviations are given in the Table 6

CCA results from dinocyst abundance in the RSA (Figures 50 and 51) revealed the relationship of dinocyst density with 11 surface sediment organic matters and sediment grain

size (GS) variables in different stations. The position of the species and sample sites on the CCA biplot diagram show their species composition and their connection to the organic matter and GS. The length of organic matter arrow and their ordination display their relative importance and approximate correlation to the axis (Figure 47). Based on Forward Selection (Table 11A) and Monte Carlo test of the 12 organic matters, EOM, TDDTs, Chrysene, and Carbonate % were statistically significant (p-value ≤ 0.05). The results of CCA showed that 37.7 % of the total inertia (3.019) in the species data was explained by sediment organic matter variables (Table 11B).

The inter-set correlation of sediment organic matter variables with the CCA axes showed that Extracted Organic Matter (EOM) was strongly related to the axis 1, and Total HCHs to the axis 2 (Table 12). Species are classified into four groups based on correlation with specific organic matter parameters. The first group that is dependent on TDDHs and TDDTs, are: *P. leonis, G. membranacea (Gome), Protoperidinium shanghaienseB (PrsB), Cochlodinium polykrikoides (Copo), Diplopsalis lenticula (Dile), Alexandrium affins (Alaf) and Scrippsiella trochoidea (Stro*), which have a positive correlation with TDDHs and TDDTs. *P. hartmanii, P. conicoides (Prcd), C. opresom (Caop), P. stenii (Pyst), L. polyedrum (Lipo), P. bahamens (Pyba), S. mirabilis (Spmi), P. compressum (Prco), P. punctulatum (Prpu)* are positively correlated with TPHs, TOC, TUS, EOM, TPCBs and carbonate parameters. These species have a negative correlation with Chrysene, Oil, TPAHs and GS. Species in the third quarter include *P. denticulatum* (*Prde), Protopredinium sp7 (Psp7), S. ramosus (Spra), P.conicum (Prcm), Protopredinium* sp1 *(Psp1)* and *P. latissimum (Prla)* that have a positive correlation with Chrysene and Oil; and a negative correlation with TDDHs, TDDTs, TPHs, TOCs, TUSs, EOMs, TPCBs, and carbonates. The *P. avelana (Prav0, S. irregularis (Scir)* and *P.claudicans (Prcl)* species are not correlated with any of the TDDHs, TDDTs, TPHs, TOCs, TUSs, EOMs, TPCBs, carbonates, and TPAHs. This is because of their proximity to the center axis (zero). *Gonyaulax cf. scrippsae (Gosc)* and *P. reticulatum (Prre)* species are positively correlated with GS and TPAHs.

Table 11: (A) Forward selection analysis of surface sediment organic matter (B) Results of DCA analysis for the first four axes

Variable%	P_{value}	LambdaA	Variable
23	0/02	0/23	Extracted Organic Matter (EOM)
26	0/002	0/26	Total DDTs
21	0/03	0/21	Chrysene
15	0/122	0/15	Total HCHs
18	0/048	0/18	Carbonate%
18	0/048	0/18	Total PAHs
14	0/202	0/14	Grain size (GS)
11	0/382	0/11	ROPME Oil equivalent (oil)
9	0/494	0/09	Total PCBs
6	0/796	0/06	Total PHs
10	0/428	0/1	Total Unresolved (TUS)
9	0/668	0/09	Total Organic Carbon % (OC)

B)

Axes	1	2	3	4	Total inertia
Eigenvalues	0.422	0.296	0.215	0.206	3.019
Species-environment correlations	0.917	0.948	0.909	0.957	
Cumulative percentage variance of species data	14.0	23.8	30.9	37.7	
Species-environment relation	23.5	40.0	52.0	63.4	
Sum of all canonical eigenvalues					1.796

Table 12: Interest correlations between first two species axes and organic matter variables in Canonical Correspondence Analysis (CCA) in the surface sediment of RSA, Winter 2006

Variable	Axis 1	Axis 2
TUS	*-0.2261	0.1706
TPHs	-0.1808	*0.3049
TPAHs	0.1366	*-0.4672
THCHs	0.1003	*0.4841
TDDTs	0.1047	*0.4781
TPCBs	-0.0630	0.0569
EOM	*-0.4815	0.3308
TOC	*-0.3177	0.2699
Carbonat	*-0.4736	0.2292
Chrysene	-0.1968	*-0.2725
Oil	-0.2013	*-0.2647
Gs	0.0820	-0.0805

Parameter with the * shows higher correlation

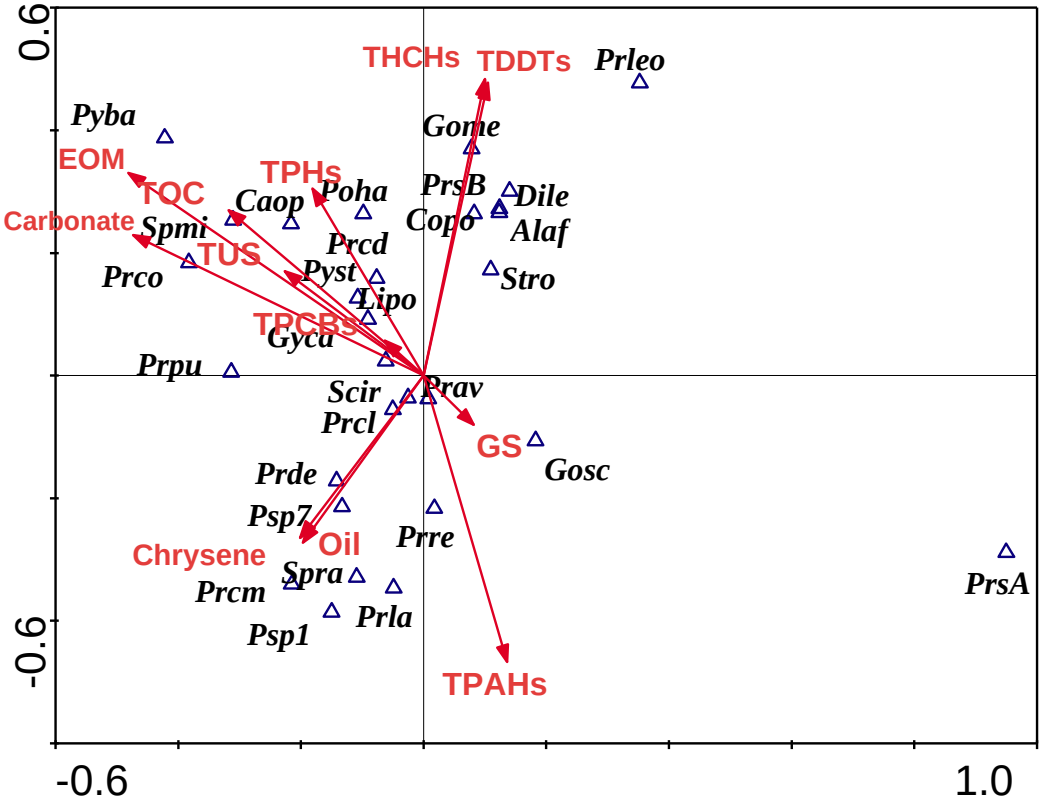

Figure 50: Ordination Diagram for the first two principal axes in the CCA analysis for dinocyst abundance of the surface sediment associated with level of organics variables in Cysts Samples Surface Sediments at RSA, Winter 2006

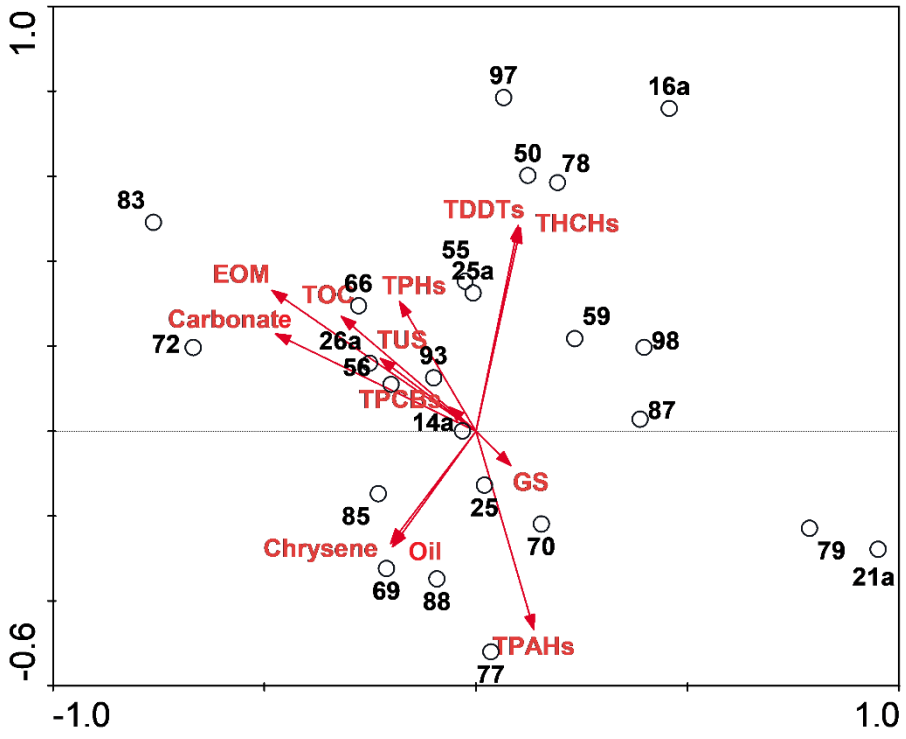

Figure 51: Ordination Diagram for the first two principal axes in the CCA analysis based on sites and with level of organic variables at RSA, Winter 2006

CCA results of dinocyst abundance in the RSA (Figures 52 and 53) display the relationship of 29 dinocyst abundance with 18 surface sediment levels of metals variables in different stations. The position of the species and sample sites on the CCA biplot diagram show their species composition and their connections to the level of metals. The length of metals arrow and their ordination display their relative importance and approximate correlation to the axis (Figure 52). Vanadium, Aluminum, Iron, Cobalt and Manganese were statistically significant (p-value ≤ 0.05) based on Forward Selection (Table 13A) and Monte Carlo test of the 18 metals. The results of CCA showed 45.7% of the total inertia (3.084) in the species data explained by level of metals in the sediment organic matter variables (Table 13B).

Table 13: (A) Forward selection analysis of Metal in the surface sediment (B) Results of DCA analysis for the first four axes

Variable%	P value	LambdaA	Variable
23	0/036	0/23	V
32	0/008	0/32	Al
21	0/04	0/21	Fe
19	0/096	0/19	Sr
19	0/084	0/19	Li
19	0/026	0/19	Co
17	0/04	0/17	Mg
15	0/128	0/15	Pb
13	0/152	0/13	Hg
13	0/116	0/13	Ca
13	0/144	0/13	Zn
10	0/272	0/1	Mn
11	0/246	0/11	Gs
9	0/386	0/09	Ba
9	0/318	0/09	Sn
7	0/442	0/07	Ni
10	0/28	0/1	Cd
8	0/418	0/08	As

(B)

Axes	1	2	3	4	Total inertia
Eigenvalues	0.546	0.338	0.280	0.244	3.084
Species-environment correlations	0.994	0.983	0.970	0.934	
Cumulative percentage variance of species data	17.7	28.7	37.8	45.7	
Species-environment relation	20.4	33.0	43.5	52.6	
Sum of all canonical eigenvalues					2.093

The inter-set correlation of sediment organic matter variables with the CCA axes (Table 14) display that the heavy metal sternum (Sn) was strongly related to the axis 1 and the heavy metal, cadmium (Cd) to the axis 2. Dinocyst species are classified into four groups based on correlation with specific level of metal in the sediment parameters. *D. lenticula (Dile), G. membranacea (Gome), G. cf. scrippsae (Gosc), P. bahamense(Pyba), A. affins (Alaf), C. polykrikoids (Copo), S. trochoidea (Stro), P. leoni (Prleo*) species have positive correlation with Mn, Pb, Hg, As, Cd and Sn; with increasing the level of the metals their abundance increase. *P. shanghaienseB (PrsB), P. hartmanii (Poha), P. conicoides (Prcd), S. mirabilis (Spmi), P. stenii (Pys)t, L. polyedrum (Lipo), S. irregularis (Scir), P. compressum (Prco)* species have positive correlation with Sr, Ca and Cd.

The abundance of species located in the third quarter, including *P. avelana (Prav), P. latissimum (Prla), P. reticulatum (Prre), G. catenatum (Gyca), P. punctulatum (Prpu), P. denticulatum (Prde), S. ramosus (Spra), Protopredinium sp1 (Psp1), P. conicum (Prcm), Protopredinium sp. 7 (Psp7)*, did not have a significant correlation with these metal elements. The PrsA species was correlated with the elements Sn, Ba, Mg, Co, Ni, Zn, Fe, Gs, V, Li and Al.

Table 14: Interest correlations between first two species axes and organic matter variables in Canonical Correspondence Analysis (CCA) in the surface sediment of RSA, Winter 2006

Variable	Axis 1	Axis 2
As	0.1508	0.2322
Cd	0.0190	*0.4303
Sn	*0.5509	-0.0331
Hg	0.0767	0.0625
Pb	*0.3529	0.0301
Zn	*0.3098	-0.1461
Mn	*0.3842	0.0268
Ba	0.2623	-0.0664
Li	0.2500	-0.2582
V	*0.3820	-0.1937
Co	*0.3134	-0.0854
Grain size (GS)	*0.3153	-0.1773
Ni	0.2886	-0.0785
Al	0.2481	*-0.2513
Ca	-0.3124	*0.3331
Fe	0.2934	-0.1587
Mg	0.2687	-0.0517
Sr	-0.2005	*0.4573

Parameter with the * shows higher correlation

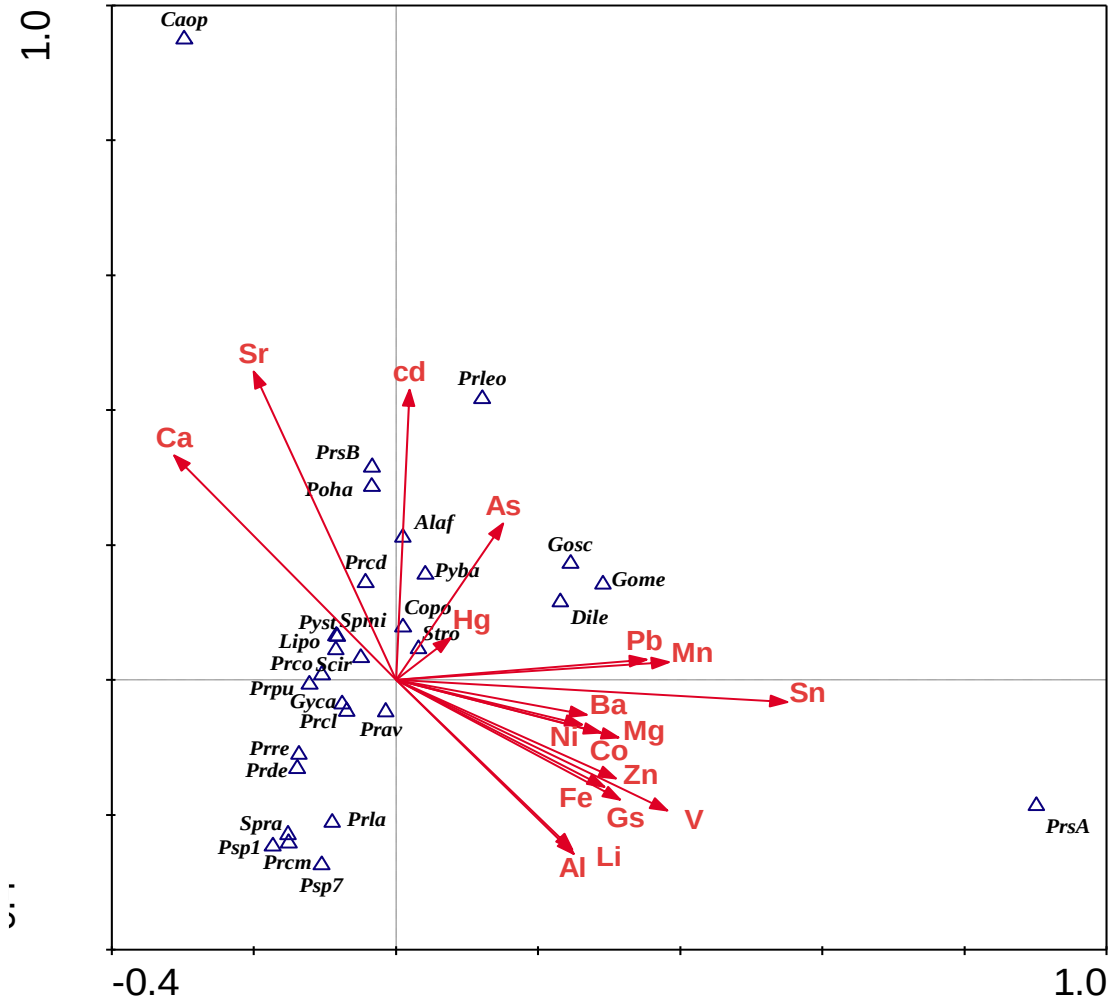

Figure 52: Ordination Diagram for the first two principal axes in the CCA analysis for dinocyst abundance of the surface sediment associated with level of metals variables in Cysts Samples Surface Sediments at RSA, Winter 2006

According to the CCA biplot diagram (Figure 53), As has a negative correlation with Mn. Pb, Mn, Sn, Ba, Li, Co, V, GS, Ni, Al, Fe and Mg. Additionally, these also have a positive correlation with each other in the sediment. Cd has a negative correlation with Sr and Ca

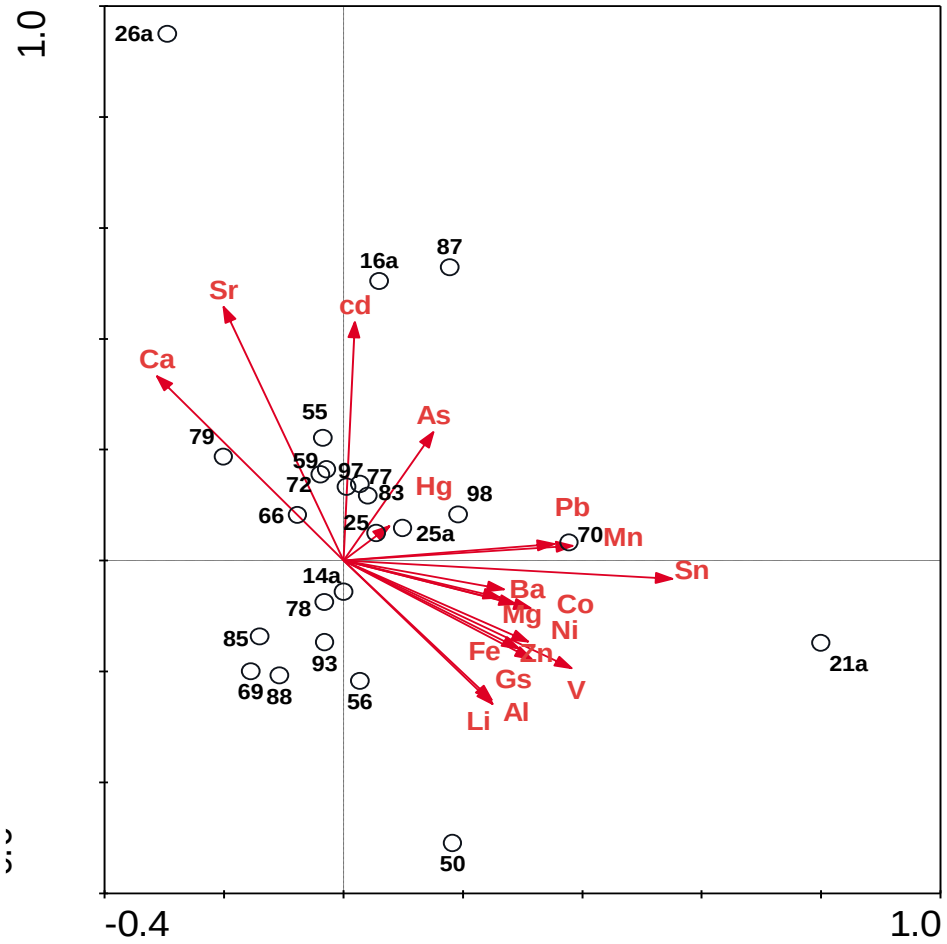

Figure 53: Ordination Diagram for the first two principal axes in the CCA analysis based on sites and with Levels of Metals variables in Cysts Sample Surface Sediments at RSA, Winter 2006

4. Conclusion

The study of phytoplankton cyst flora from ROPME Sea Area (RSA), including the Sea of Oman and the Inner part of the RSA provides useful information about cyst bed distribution, composition and presence of some cyst species that have not been reported previously from RSA.

This study was also an effort to significantly increase the knowledge of the cyst flora in a tropical region. Phytoplankton cysts of the tropical and subtropical areas are poorly described, compared with temperate regions, especially in the RSA.

The main findings of this study can be summarized as following:

- The phytoplankton cyst taxonomy of the RSA from recent surface sediment (provided as a separate monograph with taxonomical description of each cyst type) can be used as a guide for further cyst studies of the RSA.

- The number of identified cyst species in this study is very high in comparison with other areas. Approximately 47% of the species, which have been identified from different coastal areas around the globe so far, are present in the ROPME Region. However, the cyst concentration was low in comparison with other areas.

- As over the past decade, HABs significantly have increased in magnitude, frequency, and geographical extension in the coastal areas around the globe (Anderson *et al.* 2012), and also in the RSA. This investigation has put emphasis on the spatial distribution of the potential HABs forming cyst species.

- The assemblage of dinoflagellate cysts in the RSA is characterised by an overall high proportion of six cyst genera among 30 identified genera; namely, *Protopredinium, Lingulodinium, Gonyaulax Scrippsiella, Pyrophacus, Gymnodinium* and *Cochlodinium*. In this study, heterotrophic *Protopredinium* spp showed higher abundance, due to its higher number of species according to the results with 26 species. It was the most diverse genus. Ismael et al. (2014) reported that *Protopredinium* spp contributes about 43% of the total cysts in the tropical region of the Egypt. Heterotrophic dinoflagellate cysts have positively correlated with diatom concentration in the water column and total nitrogen and phosphate (Ismael et al. 2014). However, the species with highest abundance was not belonging to this genus.

- In the RSA sediments of Winter 2006, *Lingulodinium polyedrum* is a potentially bloom forming Species and the most common cyst type among phytoplankton cysts, which was recorded from almost all sites. High concentration of this species is associated in the areas with stratified water column such as the Inner RSA, and also high concentration of input nutrients (Bradford and Walls, 1984; Marret and Zonneveld, 2003). However, in the studies conducted in later years by Attaran-Fariman 2007; Attaran-Fariman *et al.*, 2014; and Attaran-Fariman 2016, in the Sea of Oman, the abundance of *L. polyedrum* species was not high in the shallower coastal areas. *L. polyerum* appears to be abundant at a depth of more than 25m and in the shallower coastal areas. *S. trochoidea* is usually abundant species in the tropical RSA area.

- It has been documented that specific cyst assemblages are associated with a specific depth, climate conditions and environmental conditions (Wall *et al.* 1977). Some species such as *Scrippsiella trifida* are restricted to temperate areas (Joyce 2004; Head *et al.* 2006), some such as *Bitectatodinium spongium* Zonneveld & Jurkschat and *Pyrodinium bahamense* are restricted to tropical to subtropical areas (Zonneveld & Jurkschat 1999; Azanza *et al.* 2004) and some such as Spiniferites group seems tolerant to extreme environmental conditions (Ismael *et al.*, 2014).

- Some species such as *Nematosphaeropsis labyrinthus* that were obsereved in the sediment of the RSA in very low density in Winter 2006, have also been reported as oceanic species with a very few exceptions (Zonneveld *et al.*, 2013). In the RSA, *S. trifida* was found in the sediment of station 40 from depth of 86m with only one individual. The presence of this species in the surface sediments of the RSA Region revealed a wide distribution of the species. This indicates the high environmental tolerance of some species such as *S. trifida*.

- Previous studies on dinoflagellate cyst assemblage of open ocean waters have demonstrated that calcareous dinoflagellate cysts are main components of the cyst flora in the tropical and subtropical areas (e.g. Dale and Dale, 1992; Holl *et al.* 1998, 1999; Attaran Fariman *et al.*, 2012). In this study, 11 calcareous dinocyst were found in the RSA; namely, *Scrippsiella. trochoidea, S. trifida, S. precaria, S. regalis, Calciperidinium asymmetricum, Calciodinellum albatrosianum, Calciodinelum opresom, Leonella Janofske Pentapharsodinium tyrrhenicum, Pentapharsodinium cf. tyrrhenicum, Bicarinellum tricarinelloides.* Among these, *C. albatrosianum, C. opresom,* and *L. granifera* are warm water species and mainly reported from fossil record (Montresor *et al.* 1998). *C. albatrosianum* and *C. opresom* are found in the stable environment condition (Wendler, 2001). *L. granifera was* reported in high abundance in the Arabian Sea during the Nederlands Indian Ocean Programme (NIOP) in 1992-1993. High abundance of this species in the NE Arabian Sea is related to the high surface temperature, low seasonality and also the influence of Indus River (Wendler, 2001) This species was found in four stations of RSA with very low abundance.

- In tropical areas such as RSA, Arabian Sea, South China Sea and Malampaya Sound coast in the Philippines, the cyst assemblage is typically affected by

monsoon currents (Zonneveld 1997; Sato *et al.* 2000; Attaran-Farimen 2016). However, in the present study, we have only the winter season (NE monsoon), therefore, it is impossible to discuss the effect of monsoon on dinocysts.

- From HABs prospective, compared with other tropical or subtropical coastal cyst assemblages from the southwest India, or the Gulf of California, Manila Bay in the Philippines (Godhe *et al.* 2000; Morquecho & Lechuga-Dveze 2003; Azanza *et al.*, 2004), the ROPME Sea Area assemblages contain consistent occurrence or higher concentration of potentially toxic species. These toxic species include *Lingulodinium polyedrum Gymnodinium catenatum Protoceratium reticulatum, Pyrodinium bahamense, Cochlodinium polykrikoids, and Scrippsiella trochoidea Alexandrium affins.* The other HABs forming Species in the RSA, with less occurrence and concentration, are *Alexandrium* spp *Polykrikoids harmanii*, and *Heterosigma* cf. *akashiwo.*

- **One of the most important findings** of this study is the presence of *Cochlodinium polykrikoides* cyst in the sediment of 11 stations out of 27 stations in the RSA in 2006. The bloom of this fish killing dinoflagellate species has also been reported from tropical and warm temperate and also temperate regions (Nuzzi and Waters, 2004; Gobler *et al.*, 2012; Tomas and Smayda, 2008). Geographical distribution of the species in many countries has been addressed (Figure 54). The first bloom of this species occurred in the RSA during 2008. Many questions have been raised by researchers about the catastrophic blooms of this species in the RSA and the mechanism of the species bloom in the area. Hallegraeff (2015) raised the issue about the introduction of harmful dinoflagellate *Cochlodinium polykrikoides* to the RSA by ballast water or the species presence in low concentration but its stimulation by changing environmental conditions such as anthropogenic nutrient enrichment. He has also urged, “an intensive effort looking for *Cochlodinium* cysts in the sediment may resolve this important question”. The present study highlights the important presence of some cyst species including *C. polykrikoids* in the sediment of RSA in 2006 that answers many questions about introduction of the species, which can serve as inocula for bloom events in the RSA.

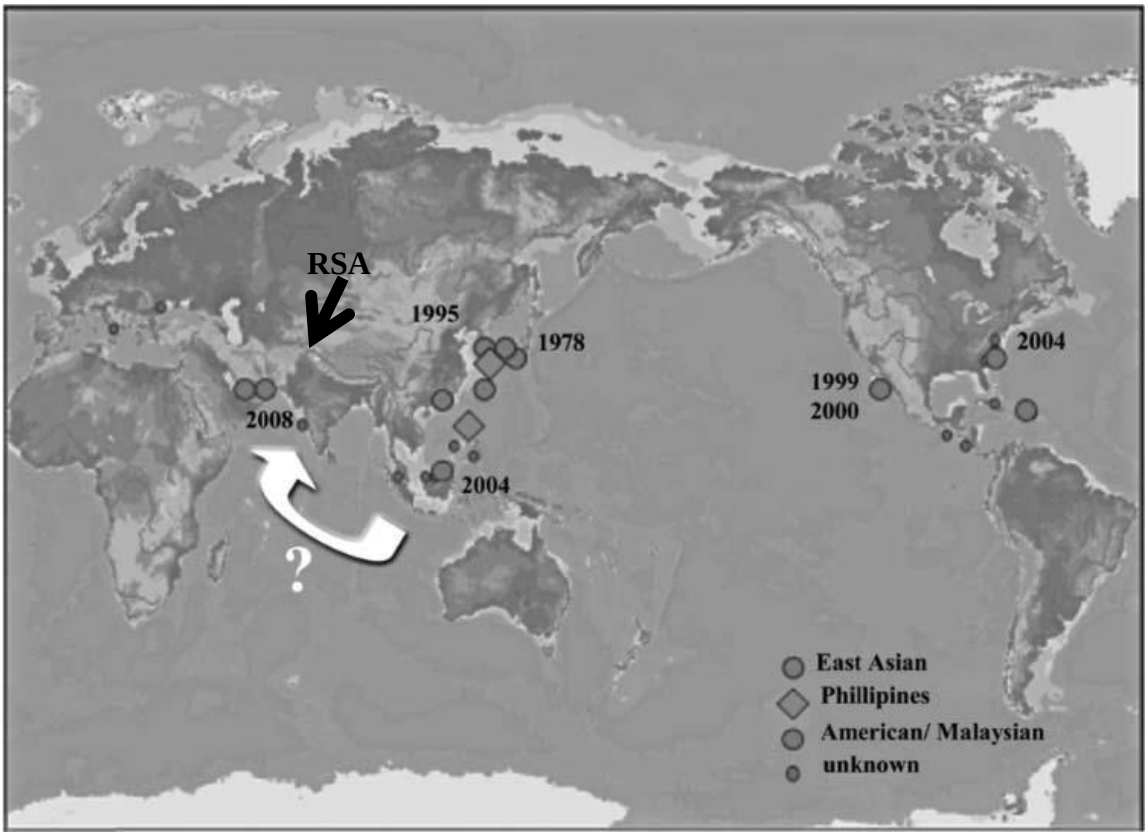

Figure 54: Geographical distribution of the C. polykrikoids showing its first HAB occurrence in different areas (after Hallegraeff, 2015)

According to the CCA biplot result on dinocyst abundance, the effect of heavy metal variable on *C. polykrikoids* revealed that increasing the amount of heavy metals - Mn, Pb, Hg, As, Cd, Sn and organic contaminants; total DDHs, total DDTs in sediment increase the cyst concentration of the species. Chlorophyll and phosphate are negatively correlated with the abundance of the cyst species. The cysts accumulation in the RSA sediments contain hidden species, which may provide a source of appearance in the planktonic assemblage, including toxic species. The effects of organic contaminants and some heavy metals on cysts of dominant species have been investigated and reported in the present study.

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REGIONAL ORGANIZATION FOR THE PROTECTION OF THE MARINE ENVIRONMENT (ROPME)

P.O.BOX: 26388, SAFAT – 13124, STATE OF KUWAIT
Tel: (965) 22093939, Fax: (965) 24864212 / 24861668
Granada, Jamal Abdul Nasser Street, Area:3,
Email: ropme@ropme.org