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Plankton research in the ROPME Sea Area, Achievements and Gaps

Dorgham, M. M.

Oceanography Department, Faculty of Science, Alexandria University, Egypt

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ABSTRACT: Plankton studies are one of the major items of the marine scientific activities in the ROPME Sea Area, whereas numerous investigations have been conducted on the plankton during the past century. For phytoplankton, species composition, abundance and biomass, primary production, harmful algal blooms, red tide, toxic species, and eutrophication were considered. Zooplankton studies included species composition and abundance**,** certain zooplankton groups and few studies on certain species. The main achievement of these studies was the identification of large number of phytoplankton and zooplankton species in different parts of the RSA and estimation of their abundance.The survey of these studies revealed the occurrence of several gaps in the plankton research in ROPME Sea Area. For example, the majority of these studies were carried out in the inner part, while some of them were done in the middle part. Several studies were based on samples collected once only during certain time of the year or on samples collected from localized areas. The role of the function groups of the both phytoplankton and zooplankton, the harmful algal blooms, toxic phytoplankton species, the role of small phytoplankton groups rather diatoms and dinoflagellates and vertical migration of zooplankton were little concerned. In addition, the continuous record of the Indo-Pacific species entering the inner RSA from the Sea of Oman appeared to be completely missed.The present study attempts to stress the achievements as well as the gaps in the earlier plankton studies in the ROPME Sea Area in order to propose a scientific plan for comprehensive study of plankton community relative to the prevailing environmental conditions in the concerned area.

Key words: Plankton in ROPME Sea Area, Phytoplankton, Zooplankton, Plankton gaps, Plankton achievement

INTRODUCTION

Plankton are essential component in the aquatic life as they play fundamental role in the biodiversity and bio-productivity of the aquatic ecosystem. They also play a crucial role in the food chains and food webs, whereas Phytoplankton represent the primary producers of organic matter, and zooplankton are the link between the phytoplankton and higher trophic levels. In addition, plankton play a crucial role in the biogeochemical cycle of numerous chemical elements in the water. The plankton research in the ROPME Sea AREA (RSA) has started historically in 1911, when a new copepod species was identified (Pista, 1911) and a list of copepods from inner part was published (Pista, 1912). Two decades later, 34 dinoflagellate species were described from the middle RSA (Bohm, 1931), and after then until the end of the seventies of the past century no studies were conducted on the plankton in the RSA, except a few investigations (Fig.1). The actual concern of marine plankton (both phytoplankton and zooplankton) in the RSA appeared in the eighties of the past century, and grew to reach the maximum during the first decade of the current century.

*Corresponding author E-mail:Mdorgham1947@yahoo.com

A total number of 168 scientific articles were published mainly on the plankton of the RSA, including 94 articles on zooplankton and 74 articles on phytoplankton. The highest number of studies was conducted in Kuwaiti waters and in the central part of the inner part, while few studies occurred in the waters of some RSA states (Fig. 2).

The present study attempts to survey the published works on plankton communities in the RSA in order to indicate the achievements and the gaps of these studies, and to propose more realistic plan for comprehensive studies on plankton in the area.

MATERIAL & METHODS

This paper attempts to review the general features of the plankton research in the ROPME Sea area, their advantages and gaps, based upon the available published works.

RESULTS & DISCUSSION

The phytoplankton research in the RSA was concerned with several aspects, such as species

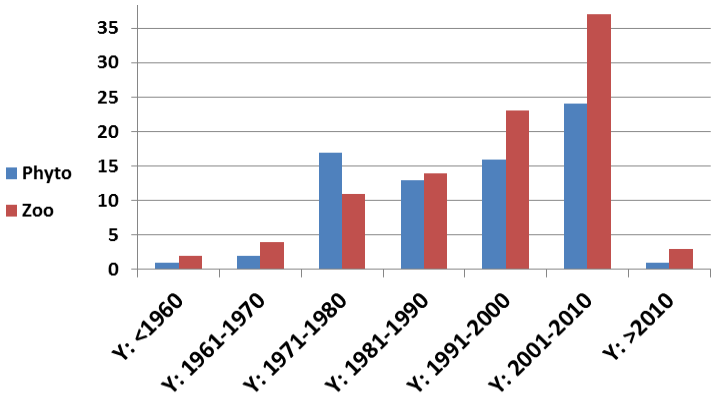

Fig. 1. The annual number of publications on plankton in RS

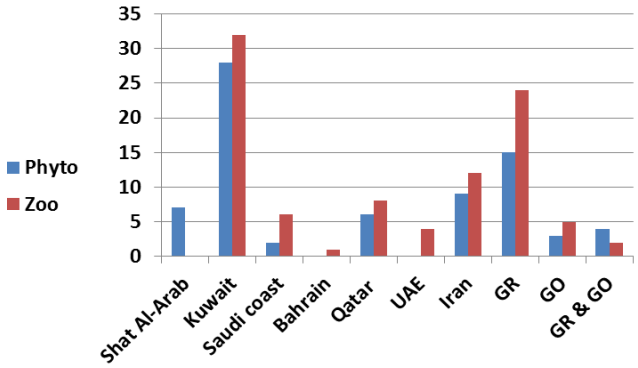

Fig. 2. Number of publications on plankton in different RS countries

composition, abundance (cell count), biomass (Chlorophyll *a*), primary production, harmful algal blooms, red tide, toxic species, eutrophication, in addition to studies on the phytoplankton-zooplankton relationship, bacterioplankton and the effect of environmental conditions on the phytoplankton community.

Species composition and abundance of phytoplankton were the main goal of numerous studies in different parts of the RSA, like Shatt-Al-Arab estuary (Saad and Antoine, 1982; Al-Saadi *et al.*, 1989), Kuwaiti waters (Al-Saadi et al, 1976**;** Jacob, 1978; 1979; Jacob *et al.*, 1979b; 1980; Al-Kaisi, 1977; Huq *et al.*, 1977; Nageeb, *et al.*, 1988; Ismail *et al.*, 1999; Al Yamani *et al.*, 2004; Piontkovski, et al. 2009; Al-Kandari et al, 2009) western part of the inner RSA (Dorgham *et al.*, 1987; Chandy *et al.*, 1991), Qatari waters (Dorgham, 1990a; 1991; Dorgham and El Samra, 1990), Iranian waters (Hulburt, *et al.*, 1981; Rezai, 1995a; Ghadikolaei, 2001; Fallahi, *et al.*, 2005; Jalilli and Rezai, 2010). Other studies were done on the phytoplankton composition throughout the inner RSA (Al-Kaisi, 1976; Jamal and Pavlov, 1979; Al-Saadi *et al.*, 1987; Habashi *et al.*, 1993; Al-Harbi, 2005; Al-Yamani 2006), in the outer RS (Hussein and Ibrahim, 1998) or in the whole RSA (Dorgham and Muftah, 1989; El-Gindy and Dorgham, 1992).

Particular attention was devoted to the major phytoplankton groups (diatoms and dinoflagellates), whereas diatoms were studied in Kuwaiti sediments (Hendy, 1970), in Iranian water (Fatemi *et al.*, 2005) and in the inner RSA (Oshite, 1974a;b). A guide to marine dinoflagellates and bloom forming phytoplankton in the RSA was prepared by Rezai (2010) and a number of dinoflagellate species were recorded in the inner RSA (Bohm, 1931) and in Qatari waters (Al-Muftah, 1991).

Phytoplankton biomass expressed as chlorophyll *a* was measured in Shatt Al Arab Estuary (Al-Handal and Hashim, 1990), in Kuwaiti waters (Jacob, 1978; 1979; Jacob *et al.*, 1979b), in Saudi waters (Abdul Aziz, *et al.*, 2003), in Iranian waters of the inner RSA (Ghadikolaei, 2001), throughout the inner RSA (Habashi *et al.*, 1993; Nezlin, *et al.*, 2007), in the Sea of Oman (Al-Azri, et al 2010; Piontkovski, et al. 2011) and in the whole RSA (El-Gindy and Dorgham, 1992). On the other hand, the primary production was measured in Shatt Al-Arab estuary (Hadi *et al.*, 1989), in Kuwaiti waters

(Huq, *et al.,* 1978; Al-Yamani *et al.,* 2005; 2006a) and in the inner RSA (Hirawake, *et al.,* 1998).

The negative effect of phytoplankton such as the red tide, toxic species, eutrophication and exotic species have drawn the attention of several investigators. The red tide was recorded in Kuwaiti waters (Glibert and Heilm, 1999; Glibert *et al.,* 2002a;b; Subba Rao *et al.,* 1999a; 2003) and the toxic algal blooms were observed in the inner RSA (Al-Yamani et al. 2002), while a number of toxic dinoflagellates was observed in Qatari waters (Yoshida *et al.,* 1997; Al-Muftah, 2008), in Iranian waters (Rezai, *et al.,* 2009) and in other parts of the inner RSA (Richlen et al. 2010). Eutrophication was reported in Shatt-Al-Arab estuary (Saad, 1984) and in Kuwaiti water (Ismail *et al.,* 2007), but exotic species transported to the inner RSA by ship ballast water was reported in the United Arab Emirates (Hamza, 2006) and in Iranian waters (Jalili *et al.,* 2008).

The effect of different environmental conditions on phytoplankton were followed up in the RS, such as the relation between phytoplankton and euphotic zone (Subba Rao and Al-Yamani, 1999) the relationship between climatic conditions and phytoplankton (Nezlin *et al.,* 2010), effect of pollution on Phytoplankton (Saad and Antoine, 1983; Valavi, *et al.,*1993), phytoplankton ecology (Subba-Rao and Al-Yamani, 1998), Eolian dust effect on phytoplankton (Subba Rao *et al.,* 1999b), phytoplankton blooms associated with a cold eddy (Tang *et al.,* 2002), eutrophication indices (Taebi *et al.,* 2005), and Phytoplankton Responses to Hurricane Gonu (Wang and Zhao, 2008).

Gaps

Although there are numerous achievement in the phytoplankton studies in the RSA several gaps could be reported, which are summarized in the following points: 1-The greatest majority of the plankton studies were carried out in the inner RSA, while little was done in the middle RSA, 2- The studies made throughout the inner RSA were concentrated on the offshore waters and neglected the coastal waters, 3- The conducted studies in the inner RSA reflect the little concern with the plankton research in most states of the area, except for Kuwait, 4- Numerous of the plankton studies were conducted in localized parts or in the water of certain states, 5- With a few exceptions, all studies were based on one time collection, 6- The species composition of plankton community appeared as the main concern of the majority of investigations in the RSA, particularly the inner part, and most of the studies have been achieved two decades ago, 7- The great discrepancies in species composition of phytoplankton community throughout the inner RSA (Table 1) can be attributed to several facts, like the differences in sampling date, frequency and regularity of sampling, number of sampled stations, methods of phytoplankton collection (net and/or water samples), depth of collection (Surface only or other depths), in addition to several other factors, 8- The real distribution of plankton community in the RSA is not clear from the published works due to the intermittent collection of samples and fragmented studies, 9- The relationship between the nutritional conditions in the RSA is not described clearly, 10- The minor phytoplankton groups like Cyanophyceae, Prymnesiophyceae, Dictyochophyceae, Cryptophyceae, Prasinophyceae, Euglenophyceae and Ebriidae were not studied, 11- The invasive species entering the RSA throughout the ship ballast waters were completely missed in the earlier studies, 12- The spatial distribution, abundance and frequency of the harmful algal blooms in the RSA were rarely tackled in the earlier studies, while several accidences of fish mortality were reported in the RSA due to harmful algal blooms (Glibert *et al.,* 2002a,b).

Zooplankton research has received more attention than phytoplankton, particularly in the inner RSA. Although the first comprehensive study on composition and abundance of zooplankton in the whole RSA was done during winter 2006 by ROPME (Dorgham, *et al.,* 2008), several intermittent studies were carried out earlier in the inner RSA (Frontier, 1963a; 1963b; Yamazi, 1974; Michel, 1979, 1980; 1983; Basson *et al.,* 1977; Michel *et al.,* 1981; 1986a; Gibson *et al.,* 1980a;b; Al-Yamani *et al.,* 1994; 1998). Other studies concerned with one or more zooplankton groups in the waters of some ROPME States, such as Kuwaiti waters (Michel, *et al.,* 1980; 1981a;b; 1982; 1983; 1986b; Fahmi, *et al.,*1987; Salman, *et al.,* 1990; Al-Yamani *et al.,* 1993; 2004; 2011; Batang, *et al.,* 2007; Jayalakshmy, 2010), in Saudi waters (Bakr *et al.,* 2004; Baker and Hosny, 2005), in Qatari waters (Dorgham and Hussein, 1991; 1997; Hussein, 1992; Ghobashy *et al.,* 1994; Nour El-Din, and AL-Khayat, 2001; Nour El-Din, 2004;), in United Arab Emirates waters (Sharaf and Al-Ghais, 1997; El-Serehy, 1998; 1999) and in Iranian waters (Rezai, 2009). Furthermore, some information were included on both phytoplankton and zooplankton community in studies conducted off Kuwait (Jacob *et al.,* 1979a;.Jacob and Zarba, 1979; 1980; Al-Yamani, *et al.,* 2004; 2006b),off Qatar (Nour El-Din, and AL-Khayat (2005) and off Iran (Fallahi, *et al.,* 2003).

Certain zooplankton groups were the main item of several studies in localized areas. Copepods were studied in Kuwaiti waters (Al-Yamani *et al.,* 1995; Al-Yamani and Prusova, 2003), in Qatari waters (Nour El-Din and Ghobashy, 1999), in the inner RSA (Pista, 1912; Prusova *et al.,* 2001), in the middle RSA (Al-Khabbaz and Fahmi, 1998; Fazeli *et al.,* 2008; 2010; Fazeli and

Table 1. Number of phytoplankton species recorded at different parts of the RSA

Area	Diatoms	Dinof	Blue green	Silicof	Total	Reference
Shatt Al-Arab	Dominant				116	Hadi et al. 1989
Shatt Al-Arab	Dominant				95	Saad and Kell 1975
Shatt Al-Arab	Dominant				77	Hinton and Maulood 1980
Shatt Al-Arab	Dominant				90	Hulburt et al. 1981
Kuwait Coast	39	4				Enomoto (1971
Kuwaiti waters	92	38		1	131	Dorgham et al. 1987
Kuwaiti waters	134	56	2		200	Polikarpov et al., 2009
Kuwaiti waters	202	108	2		323	Al Kandari et al., 2009
off Kuwait	135	13				Al-Kaisi 1976
Saudi Coast	161	14	16		192	Basson et al. (1977)
Saudi Coast	88	56	2	1	147	Dorgham et al. 1987
Western GR	134	86	2	1	223	Dorgham et al. 1987
Qatari waters	87	68	2	1	158	Dorgham et al. 1987
Qatari waters	284	225			510	Dorgham 1991
off Qatar	225	152	11	1	389	Dorgham and Muftah 1986
Doha Harbour (Qatar)	187	148			343	Dorgham 1990
Iranian waters		34			34	Bohm 1931
ROPME Sea Area	416	68	16	12		Al-Saadi and Hadi (1987
RSA Region					86	Husain and Ibrahim, 1998
Inner RSA Region	175	124			299	Dorgham and Muftah 1989
Sea of Oman	54	92			146	Dorgham and Muftah 1989
Iranian area	124	114	5		244	Fallahi et al., 2005
Bushehr area (Iran)	97					Fatemi et al., 2005
Northern RSA	44	18				Ghadikolaei k, R. (2001)
Whole RSA	888	211		15		Jacob and Al-Muzaini (1990, 1995)
Central RSA	80	43		1		Al-Harbi, 2005

Zare, 2011). Studies on Larvacea and other urochordates were conducted in Iranian waters (Eftekhar *et al.,* 2008; 2011) and in the inner RSA (Fenoux, 1973), while other studies were concentrated on chaetognatha in Iranian waters (Haghi *et al.,* 2007; 2010) and in the inner RSA (Furnestin and Codaccioni, 1968; Michel, 1995). Some planktonic molluscs and the ratio between Planktonic and-benthic molluscs in sediments were studied off Iranian Coast (Sarnthein, 1967; Rezai, 1995b), and crustacean Mysidacea off Bahrain (Grabe et al, 2004). Except that of Houde (1979) no studies were carried out on Ichthyoplankton in the RSA.

The ciliate protozoans (Tintinnids) have received particular attention in Kuwaiti waters (Al-Yamani and Skryabin, 2006; Skryabin and Al-Yamani, 2006; 2007b, 2007c), in Qatari waters (Dorgham and Abdel-Aziz, 2001), in the inner RSA (Martini, 1969) and in the whole RSA (Dorgham, 1990b). However, little attention was drawn to these protozoans in the other parts, except that conducted on foraminifera in the inner RSA (Cherif *et al.,* 1997). One study only was done on bacterioplankton in Kuwaiti waters (Al-Rifaie *et al.,* 2008).

A number of species attracted the attention of some investigators, such as new species of tintinnids (Skryabin and Al-Yamani, 2006; 2007a) and copepods (Ali, *et al.,* (2007) in Kuwaiti waters. The distribution of certain zooplankton species was studies in Kuwaiti waters, like the copepod *Acartia* (Pista, 1911; Ali *et al.*, 2009), the cladoceran *Podon* spp aters (Ali, 2010) and *Noctiluca scintillans* (Al-Azri *et al.,* 2007).

The meroplankton study in the RSA is little known, except the larvae of shrimps (Price, 1979; 1982; Price and Andew, 1979; Andrew and Price, 1982; Price *et al.,* 1991; 1993; Grabe and Lees, 1995a) and larvae of crabs (Al-Aidaroos, 1993; Grabe and Lees, 1995b; Al-Khayat and Jones, 1996; Al-Yamaniand Khvorov, 2007; Al-Yamani *et al.,* 2010).

Gaps

Several gaps can be reported in the zooplankton studies in the RSA and summarized in the following points: 1- Similar to phytoplankton the majority of the conducted investigations on zooplankton were based on one collection a year by using plankton nets of

different mesh size and different dimensions, 2- In some studies the collection of zooplankton samples was carried out more than one time but in irregular times, 3- The majority of the conducted studies were concentrated mainly on copepods, while the majority of other zooplankton groups were rarely considered. Some groups like Chaetognatha, Larvaceae, Cnidaria and Thaliacea which have a crucial role in the biomass of zooplankton were missed in the most zooplankton studies, 4- Most of the studies were localized to certain part or state and were done in different times, which were reflected on the pronounced differences in the number of zooplankton species throughout the RSA, 5- The comparatively high number of zooplankton species (231 species) recorded in winter 2006 (Table 2) does not represent the real species richness of zooplankton in the RSA the area, because it comprised the winter community only, particularly in the upper 10 m, 6- Except in Kuwaiti and Qatari waters, the marine protozoans have received little attention in the most part of the RSA, 7- Despite of the crucial role of meroplankton in the inner RSA as shallow basin, it was neglected in most plankton studies, 8- The continuous entrance of Indo-Pacific plankton (phytoplankton and zooplankton) species to the inner RSA through the low salinity water from the middle RSA has not received the suitable attention. In the meantime, the exit of some species from the inner RSA to the middle RSA through the deep high salinity water in the Strait of Hormuz was not also considered, 10- The phytoplankton and zooplankton in the water masses over some benthic communities, like coral reefs, sea weeds and sea grasses, mangroves, as well as in the intertidal zone were completely missed.

Based on the achievements and gaps reported in the earlier plankton studies in the RSA, we propose a plan for a comprehensive study of both phytoplankton and zooplankton in the area in order to obtain complete data and to establish a data base on the plankton communities in the concerned area.

The proposal depends upon regular (at least seasonal) survey of plankton communities and hydrographic conditions along the water column at fixed stations throughout the RSA to do the following items:

1-to study the complete species composition of phytoplankton and zooplankton,

2-to obtain a complete figure for the abundance of phytoplankton and zooplankton in the whole.

3-to define the role of each group in the total plankton abundance at different parts of the RSA, and to understand the role of function groups in each part.

4-to define the role of small phytoplankton groups like coccolithophores, silicoflagellates, prasinophytes and others, which have never been studied in the area.

5-to collect more detailed information about the harmful algal blooms.

6-to study the diurnal vertical migration of zooplankton species and to discover the species live in the deep water.

7-To identify the exotic plankton species carried to the area by ships ballast waters.

In addition to the items mentioned above, other studies must be done, such as:

1-Continuous regular plankton study at fixed stations in the waters of all ROPME states to carry out a time series analysis of the collected data which help in

Table 2. Number of zooplankton species recorded at different parts of the RSA

Area	Tintinnids	Copepods	Total zoo	Reference
RSA			231	Dorgham et al., 2008
GR		30		Yamazi, 1974
GR		13		Gibson et al., 1980
Inner RSA		49	100	Michel *et al*., 1986a
GR	58			Dorgham 1990
GR			210	Dorgham et al., 2008
Saudi Coast		42	82	Bakr et al., 2004
NW GR			181	Patang *et al*., 2007
Kuwait			95	Michel *et al*., 1986b
Kuwait	73	54	174	Al Yamani et al., 2011
Off Qatar		57	130	Hussein, 1992
Off Qatar		51		Nour El Din and Ghobashy, 1999
Doha Harbour			30	Dorgham andHussein, 1997
G O			144	Dorgham et al., 2008
Chabahar Bay GO		75		Fazeli et al. 2010
G O		45		Fazeli and Zare, 2011
G O	35			Dorgham 1990

understanding the long term changes in the biodiversity of the RSA.

2-Study of the plankton communities in the water masses covering the special benthic communities, like coral reefs, salt marches, sea grasses, mangrove areas and intertidal zones.

3-Continuous record of plankton species entering the inner RSA with the low salinity water from the Sea of Oman and species leaving the inner part with high salinity water at the deeper layers. This record can be achieved by regular collection of plankton samples at different depths in the area of the Strait of Hormuz.

4-Study of the dinoflagellates cysts, particularly in the inner RSA, to define the potential of harmful algal species.

CONCLUSIONS

The plankton studies in the RSA were concentrated mainly on species composition and abundance of both phytoplankton and zooplankton. The essential gaps reported in these studies include the irregular collection of samples, the sporadic studies in localized area, the lack of integrated studies between the RSA states, the complete neglection of plankton studies in some states, the absence of comprehensive regular monitoring studies in the whole RSA. Furthermore, zooplankton vertical migration, toxic algae, harmful algal blooms, the entrance of exotic species either from the middle RSA thorough the low salinity water of by ship ballast waters were also missed in the earlier plankton studies. Regular integrated studies throughout the whole RSA are required.

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