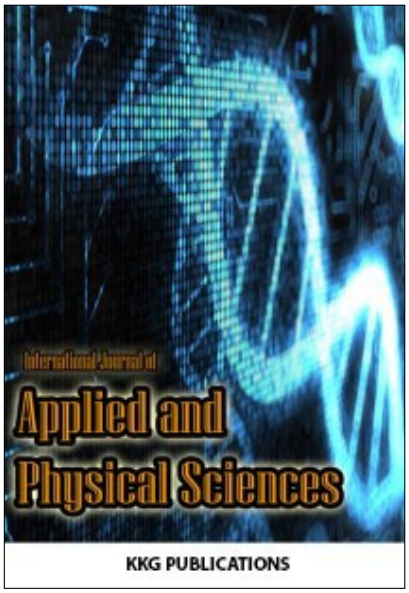

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SPATIAL DISTRIBUTION OF MARINE PLANKTONS OFF THE COAST OF SITRA, KINGDOM OF BAHRAIN

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Abstract. A study was conducted on the spatial distribution of marine plankton off-coast of Sitra, the Kingdom of Bahrain, from August 2014 - July 2015. Specifically, this research aims to determine and identify the planktons; categorize the plankton as phytoplankton and zooplankton and classify taxonomically; calculate the population size of the identified plankton based on abundance, density, and biomass. Find out significant differences in the calculated population size based on the parameter used; determine dispersion index of the identified plankton concerning spatial distribution. And monitor surface water temperature and salinity, its effect on the spatial distribution, and population size of the identified plankton. The collection of water samples was done using the towed method. Results showed 20 species of phytoplankton and 14 species of zooplankton. Of the phytoplankton, 13 species belong to Phylum Chrysophyta or diatoms, and 7 species in Phylum Dinoflagellata or dinoflagellates. The 14 species of zooplankton belong to 8 phyla- Protozoa, Cnidaria, Platyhelminthes, Rotifer, Annelida, Mollusca, Arthropoda, and Chordata. The identified species of phytoplankton and zooplankton vary in abundance, density, and biomass. Fragillariopsis and Navicula species are the most abundant phytoplankton with higher density and biomass, while Ceratium furca and Ceratium fusus for the zooplankton. Statistical analysis using ANOVA revealed significant differences at the .05 level in abundance and density. However, an insignificant difference in biomass. Based on the dispersion index, the phytoplankton and zooplankton are vertically distributed, and aggregation is mostly on the upper column where sunlight is abundant. Surface water temperature and salinity significantly affect the spatial distribution and population size of the identified marine plankton.

INTRODUCTION

It is a common observation that the earth surface is covered more of the ocean waters. The marine environment is considered the most productive ecosystem. The range of organisms make up the community structure that varies from macroscopic to microscopic. There are microscopic organisms which are considered the natural inhabitants of the marine water. These organisms are called planktons which composed the grazing productivity of any marine ecosystem. Planktons are of two types, the phytoplankton and zooplanktons are well-distributed on the water surface following the route of current. Zooplanktons are considered the major primary consumers and predators in most aquatic ecosystems. These microscopic organisms are characteristically diverse [1] which serve as food for many marine animals. The study of spatial structure is an important research in the field of ecology focused on communities of organism in marine ecosystem. The spatial distribution of planktons determines the type of structure characteristic of a natural ecosystem [2]. Marine planktons inhabit the depths of the oceans in infinite numbers. This reveals the remarkable underwater world inhabited by microscopic organisms with biomass that is characteristically the same in the upper ocean [3].

Both phytoplanktons and zooplanktons drift with current in all marine environments. Although their abundance varies according to size, their occurrence in every liter of ocean water is remarkable with 95% biomass [4]. Marine planktons exert influence on the ecosystems of the world and on the marine environments as well [5].

The marine water of the Kingdom of Bahrain is richly endowed with resources in determining community structure. Specifically, the sprawling water 3 to 4 miles off the coast of the northeastern part of Sitra served as the habitat of microscopic, surface dwelling planktons. The conservation of marine communities is integrated to the ecological web of marine life. The local abundance and spatial distribution of both phytoplanktons and zooplanktons are attributed to various factors. Considering the environmental factors, water temperature and salinity were monitored throughout the study. The effects of these factors may directly or indirectly determine the spatial distribution and population size of the identified planktons in the study site.

Objectives of the Study

This research undertaking was conducted to determine the spatial distribution of planktons off the coast of Sitra, King-

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dom of Bahrain. Specifically, this study was conducted to:

- determine and identify the planktons off the coast of Sitra, Kingdom of Bahrain;
- categorize the planktons as phytoplanktons and zooplanktons and classify taxonomically;
- calculate the population size of the identified planktons based on abundance, density, and total biomass using settled volume method;
- find out significance differences in the calculated population size of the identified planktons based on the parameters;
- determine dispersion index of the identified planktons; and
- monitor the surface water temperature and salinity, its effect on the spatial distribution and population size of the identified planktons.

LITERATURE REVIEW

Marine Planktons, Characteristics and Spatial Distribution

Planktons are small and diverse organisms that live in water column [6] of the marine water and other bodies of water. This includes variety of drifting animals, protists, archae, algae or bacteria in the pelagic zone of oceans and seas. Variation in terms of local abundance is highly influenced by sunlight and availability of nutrients. Characteristically local abundance varies seasonally, horizontally, and vertically. The effect of population size variation is on primary production which is usually concentrated on the water surface. Geographically and seasonally, this is attributed to abundant sunlight. These organisms as defined by their ecologic niche are light-dependent hence population size varies from region to region in the world oceans. Planktons are categorized into three main functional groups. The phytoplanktons referred to as the plants of the sea live near water surface with sufficient sunlight for photosynthesis. This group includes cyanobacteria, diatoms and dinoflagellates. The zooplanktons are small animals like crustaceans, small protozoan or metazoans that feed on other planktons. Included in this group are some eggs and larvae of large animals like fish crustaceans and annelids.

The interactions of the various factors such as the organism's behavior and physical oceanographic and processes determine the spatial distribution of organisms in the ocean.

Generally, planktons display a broad range of behavioral pattern that determines their vertical and horizontal distribution in the ocean. The organism's response to the physical environment influences planktonic aggregation. This then causes a direct impact on the function of marine ecosystems [7]. The variation in the dynamics of the ocean is attributed to multiple factors. Vertical migration as a global phenomenon is a characteristic of the world ocean to describe the synchronized movement of both phytoplankton and zooplankton. This phenomenon balances the need for feeding on the surface where food is abundant.

The patterns of migration are also directly controlled by solar light [8]. Individual organisms and population experience total environment variability such as upper water column of oceans and seasonal cycles [9]. The spatial distribution varies from individual plankton taxa based on the standardized number in m3 from each water sample [10]. Among the zooplankton, copepods are numerically abundant in terms of number and biomass [10, 11]. The spatial variability of planktons biomass is influenced by its size [12, 13]. The spatial distribution of organisms in the ocean is determined by interactions between the behavior of the organism and physical structure and process of the ocean water. The physical structures and processes are important driving force for the distribution and dispersal of the organism. This is attributed to the swimming and behavioral capabilities of individual species [14]. There is unlimited horizontal distribution of plankton. However, their vertical extent is constrained by the sunlit layer of the sea [15].

RESEARCH MODEL

Below is the research model of the study. The interactions of various factors determine the spatial distribution of organisms in the ocean which causes an influence on planktonic aggregation [7]. Figure 1 shows the research model of the study showing the relationship of the different variables. The spatial distribution of marine plankton 3 miles off-coast in the northeastern part of Sitra from August 2014 to July 2015 is the independent variable. The dependent variables are the identified planktons which were categorized and classified taxonomically. The population size was determined based on abundance as indicated by the number of each species per drop of water sample and number of each species per m3 of water sample, density, and total biomass using settled volume method. Dispersion index was also calculated for every change in water column of distance sampling in miles. Important environmental factors like surface water temperature and salinity were monitored which may exert direct or indirect effect on the spatial distribution and population size of plankton for the duration of the study.

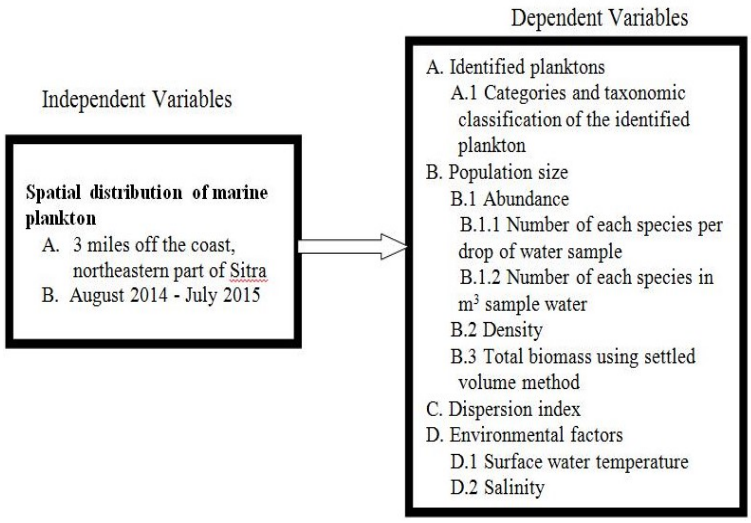

Fig. 1 . Research model

DATA ANALYSIS

TABLE 1
IDENTIFIED PLANKTONS OFF-COAST OF NORTHEASTERN PART OF SITRA, KINGDOM OF BAHRAIN, AUGUST 2014 - JULY 2015

I. Phytoplankton		II. Zooplankton	
A. Phylum Chrysophyta or Diatoms		A. Phylum Protozoa	
Genus	Species	Genus	Species
1. Biddulphia	aurita	1. Globigernia	bulloides
2. Chaetoceros	sp.	2. Radiolarian	sp.
3. Coscinodiscus	sp.	B. Phylum Cnidaria	
4. Ditylum	brightwellii	1. Actinula larvae	sp.
5. Fragillariopsis	sp.	C. Phylum Platyhelminthes	
6. Lauderia	annulata	1. Platyhelminthes	sp.
7. Lioloma	pacificum	D. Phylum Rotifera	
8. Navicula	sp.	1. Branchionus	plicatitlis
9. Proboscia	alata	2. Rotifer	sp.
10. Pseudo-nitzschia	australis	E. Phylum Annelida	
11. Rhizosolenia	sp.	1. Early trochophore polychaete larvae	sp.
12. Thalassiosira	punctigera	F. Phylum Mollusca	
13. Thalassiosira	sp.	1. Bivalve veliger larvae	sp.
B. Phylum Dinoflagellata or Dinoflagellates		G. Phylum Arthropoda	
1. Alexandrium	sp.	1. Calanoid copepod	sp.
2. Ceratium	furca	2. Harpacticoid copepod	sp.
3. Ceratium	lineatum	3. Crustacean cypris larvae	sp.
4. Ceratium	fusus	4. Crustacean nauplius larvae	sp.
5. Peridium	sp.	H. Phylum Chordata	
6. Pololampasa	palmipes	1. Fritillaria	sp.
7. Prorocentrum	micans	2. Oikopleura	sp.

The phytoplankton identified 3 miles off-coast of Sitra, Kingdom of Bahrain is composed of two major phyla, Phylum Chrysophyta or known by the common name diatoms, with 13 species and Phylum Dinoflagellata or dinoflagellates with 7 species. The dinoflagellates are mostly Ceratium species. The zooplankton with 8 phyla - Protozoa, Cnidaria, Platyhelminthes, Rotifera, Annelida, Mollusca, Arthropoda, and Chordata composed mostly of larvae, some identified and unidentified species of the 8 phyla, Phylum Arthropoda comprised the most number of species, mostly crustacean larvae and copepods. Although the phyla composition of zooplankton is more than the phytoplankton, however, in terms of species composition, phytoplankton comprised the most number. Characteristically, the local abundance of plankton varies vertically.

TABLE 2
POPULATION SIZE OF THE IDENTIFIED PLANKTON

Identified Plankton	Population Size				
I. Phytoplankton	Abundance Average number per drop sampled	Number per m^3 sampled water	Total abundance	Density (Number/m^3)	Total biomass (mL/m^3)
A. Phylum Chrysophyta (Diatoms)					
1. Biddulphia aurita	0.05	562	11	25	0.1
2. Chaetoceros sp.	0.64	7,200	144	320	0.128
3. Coscinodiscus sp.	0.11	1,238	25	55	0.22
4. Ditylum brightwellii	0.11	1,238	25	55	0.22
5. Fragillariopsis sp.	0.80	9,000	180	400	0.16
6. Lauderia annulata	0.43	4,838	97	215	0.86
7. Lioloma pacificum	0.21	2,362	47	105	0.42
8. Navicula sp.	0.80	9,000	180	400	0.16
9. Proboscia alata	0.37	4,162	83	185	0.74
10. Pseudo-nitzschia australis	0.27	3,038	61	135	0.54
11. Rhizosolenia sp.	0.11	1,238	25	55	0.22
12. Thalassiosira punctigera	0.59	6,638	133	295	0.118
13. Thalassiosira sp.	0.11	1,238	25	55	0.22
B. Phylum Dinoflagellata (Dinoflagellates)					
1. Alexandrium sp.	0.11	1,638	25	55	0.22
2. Ceratium furca	1.65	18,562	371	825	0.33
3. Ceratium lineatum	0.05	562	11	25	0.1
4. Ceratium fusus	1.12	12,600	252	560	0.224
5. Peridium sp.	0.05	562	11	25	0.1
6. Pololampasa palmipes	0.05	562	11	25	0.1
7. Prorocentrum micans	0.11	1,638	25	55	0.22
II. Zooplankton					
A. Phylum Protozoa					
1. Globigernia bulloides	0.05	562	11	25	0.1
2. Radiolarian sp.	0.21	2,362	47	105	0.42
B. Phylum Cnidaria					
1. Actinula larvae sp.	0.05	562	11	25	0.1
C. Phylum Platyhelminthes					
1. Platyhelminthes sp.	0.05	562	11	25	0.1
D. Phylum Rotifera					
1. Branchionus plicatitlis	0.05	562	11	25	0.1
2. Rotifer sp.	0.05	562	11	25	0.1
E. Phylum Annelida					
1. Early trochophore polychaete larvae sp.	0.05	562	11	25	0.1
F. Phylum Mollusca					
1. Bivalve veliger larvae sp.	0.05	562	11	25	0.1
G. Phylum Arthropoda					
1. Calanoid copepod sp.	0.05	562	11	25	0.1
2. Harpacticoid copepod sp.	0.21	2,362	47	105	0.42
3. Crustacean cypris larvae sp.	0.59	6,638	133	295	0.118
4. Crustacean nauplius larvae sp.	0.59	6,638	133	295	0.118
H. Phylum Chordata					
1. Fritillaria sp.	0.05	562	11	25	0.1
2. Oikopleura sp.	0.05	562	11	25	0.1

The population size of the identified plankton is determined based on abundance, density, and biomass as shown in Table 2. The index for abundance is the average number of species per drop sampled and the number of species per m^3 sampled sea water. Results revealed that of the phytoplankton, the diatoms Fragillariopsis and Navicula sp. had the highest average number per drop, 0.80, followed by Thalassiosira puntigera (0.59), and Lauderia annulata (0.43), respectively. Similarly, the same species incurred the highest number per m^3 of sea water- 9000, 6638, and 4883 based on species occurrence and the most abundant species as well. Whereas, Ceratium furca (#/drop/m^3= 1.65/18,562); and Ceratium fusus (#/drop/m^3 = 1.12/12,600) are the most abundant of the dinoflagellates. Results also depicted the highest density of the same species.

The zooplankton although composed of many phyla (Table 1), the radiolarian sp. of Phylum Protozoa had the highest values for the number per drop/per m3, 0.21/2363, while Crustacean larvae cypris and nauplius sp. followed with 0.59 and 6638, respectively. The same species are considered the most abundant with the highest density and biomass as well.

TABLE 3
RESULTS OF ANALYSIS OF VARIANCE (ANOVA) ON
(A) ABUNDANCE, (B) DENSITY, AND (C) BIOMASS OF THE IDENTIFIED PLANKTONS

(a) On Abundance					
	SS	df	MS	F-value	p-value
Between groups	25,723.334	2	12,861.667	199.579	0.000*
Within groups	1,997.762	31	64.444		
Total	27,721.096	33			
*The mean difference is significant at .05 level					
(b) On Density					
	SS	df	MS	F-value	p-value
Between groups	96,815.147	2	48,407.573	352.382	0.000*
Within groups	4,258.551	31	137.373		
Total	101,073.98	33			
*The mean difference is significant at .05 level					
(c) On Biomass					
	SS	df	MS	F-value	p-value
Between groups	0.200	2	0.100	0.452	0.639^{NS}
Within groups	6.826	31	0.220		
Total	7.026	33			

NS means not significant at .05 level

Statistical analysis using ANOVA (Table 3(a,b)) depicted significant differences at .05 level in terms of abundance and density of the identified planktons. The p-values for abundance and density of 0.000 and F-values of 199.579 and 352.382, respectively, hence the mean difference is significant at .05 level. However, using variance-to-mean ratio (VMR) showed a dispersion index, I_w = 161.24 for the phytoplankton while 876.156 for the zooplankton.

TABLE 4
RESULTS OF ANALYSIS OF VARIANCE (ANOVA) ON TEMPERATURE AND SALINITY AT VARYING MONTHS

	SS	df	MS	F-value	p-value
Between groups	107.104	1	107.104	3.301	0.083NS
Within groups	713.908	22	32.450		
Total	821.012	23			

NS means not significant at .05 level

Statistical analysis using ANOVA showed insignificant difference in temperature and salinity at varying sampling month at .05 level with p-value of 0.083 and F-value of 3.301.

TABLE 5
RESULTS OF ANALYSIS OF VARIANCE (ANOVA) OF TEMPERATURE-SALINITY EFFECT ON (A) ABUNDANCE, (B) DENSITY, AND (C) BIOMASS OF THE IDENTIFIED PLANKTONS

(a) On Abundance					
	SS	df	MS	F-value	p-value
Between groups	40,893.392	4	10,223.348	199.817	0.000*
Within groups	2,711.670	53	51.164		
Total	821.012	57			
*The mean difference is significant at .05 level					
(b) On Density					
	SS	df	MS	F-value	p-value
Between groups	254,741.678	4	63,685.420	678.864	0.000*
Within groups	4,972.459	53	93.820		
Total	259,714.137	57			
*The mean difference is significant at .05 level					
(c) On Biomass					
	SS	df	MS	F-value	p-value
Between groups	14,725.104	4	3,681.276	270.707	0.000*
Within groups	720.734	53	13.549		
Total	15,445.837	57			

NS means not significant at .05 level

Results of ANOVA in Table 5 (a,b,c) depicted significant temperature-salinity effect on the abundance with p-value = 0.000 and F-value = 199.817; density p-value = 0.000, F-value =678.864 , and biomass p-value = 0.000, F-value= 270.707.

DISCUSSION

Table 1 presents the identified plankton off-coast in northeastern part of Sitra, Kingdom of Bahrain. Results showed two categories of plankton, the phytoplankton and the zooplankton classified taxonomically using references [16, 17, 18]. The phytoplanktons are usually found on surface water [6] with sufficient sunlight for photosynthesis [7]. This group includes the diatoms and dinoflagellates as shown in the results of this study with 13 species of diatoms and 7 species of dinoflagellates. Ecologically, phytoplanktons are considered important producers in the marine ecosystem [17].

In Table 2, population size of the identified plankton is determined by total abundance, density and biomass. The effect of population size is on primary production [6] since the phytoplanktons are considered the producers [7] of the marine ecosystems which inhabit the illuminated [14] part of the sea water. Dinoflagellates are also considered common coastal planktons [16]. The zooplankton includes many crustacean larvae [6] which become food for other planktons [7]. The spatial distribution of planktons is influenced by the physical characteristics of the ocean water [14]. Vertical migration is also described as a synchronized movement of both phytoplankton and the zooplankton [6]. The pattern of migration is directly controlled by solar light [8]. Individual organisms and population experience environmental variability due to changes in water column and seasonal cycles [9]. Results showed spatial variability in abundance, density and biomass. The spatial variability of planktons biomass [12] is influenced by its size [13]. Different studies on plankton [14, 15, 19, 20, 21, 22] depicted biomass, abundance and density determination as these factors are also correlated to oceanographic processes and events [19], temperature [23] and behavioral patterns [8] of the organisms.

Results of statistical analysis using Analysis of Variance (ANOVA) in Table 3 imply that the number of each species varies significantly as each species occurs in every drop and m3 of sea water. The use of settled volume method [17, 18] may not be able to measure accurately the plankton biomass. This may be attributed to the time required for the plankton to settle although there is no set standard time [18].

The index of dispersion (ID) is used to describe the spatial distribution of planktons following vertical zoning, $I_w = \sigma^2/m$. Although, sampling is not of wide coverage limited only to 3.0 mi, measurement of dispersion may not be employed [2]. The use of settled volume method [17, 18] may not be able to measure accurately the plankton biomass. This may be attributed to the time required for the plankton to settle although there is no set standard time [18]. Results further showed that both the phytoplankton and the zooplankton are over dispersed characterized by negative binomial distribution. This result implies that most of the planktons aggregate on the upper strata of the vertical zone which may be in the first 2 miles.

On temperature and salinity interaction at varying months (Table 4), results imply that temperature and salinity are constant in the entire duration of the sampling. Accordingly, planktons are diverse organisms that live in water column [6] and defined by their ecologic niche [7], are light-dependent [8] which inhabit the illuminated 200 m [16] of the surface water. The vertical distribution of the planktons is influenced by the constant temperature and salinity (Table 4) of the sea water during the period of study. Results in Table 5 can be further interpreted that a temperature range of 28-33oC and salinity range of 36-38.8 0/000 are considered favorable environmental conditions of the water column for the movement of planktons following vertical path [7] related to hydrographic [12].

CONCLUSION

Based on the findings of this particular study, the following conclusions are hereby formulated:

- Planktons such as phytoplankton and zooplankton are found off-coast of Sitra, Kingdom of Bahrain.
- The identified species of plankton are categorized as phytoplankton and zooplankton which belong to different phyla composed of different species.
- The population size of the identified phytoplankton and zooplankton vary in abundance, density, and biomass.
- The abundance and density of phytoplankton and zooplankton vary significantly per drop/m^3 of sea water samples but not in biomass.
- Phytoplankton and zooplankton are vertically distributed and aggregation is mostly on the upper water column where sunlight is abundant.
- A surface water temperature of 30.40°C corresponding to a salinity of 34.57 parts per thousand are favorable environmental conditions for the spatial distribution of the identified phyto-zooplankton 3 miles off-coast of Sitra, Kingdom of Bahrain.

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— This article does not have any appendix. —