REPORT B

GENERAL BIOLOGICAL OCEANOGRAPHIC DATA FROM THE PERSIAN GULF AND GULF OF OMAN

by

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May 1978

TECHNICAL REPORT

Prepared with funds from the Iranian Department of the Environment.

Approved for Distributio

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Abstract

Quantitative phytoplankton (31 samples) and zooplankton (23 samples) collections were made throughout the Persian Gulf and at several places in the Gulf of Oman in spring 1977. In addition, 34 neuston tows were made in these areas. Approximately 100 species of phytoplankton were identified. Their numerical abundance ranged from 200 to 42,000 cells per liter. Diatoms were the most diverse taxa while coccolithophores were generally the dominant species numerically. Zooplankton biomass ranged from .11 to 2.00 cc/m^3 and .52 to 2.27 cc/m^3 in the Persian Gulf and Gulf of Oman respectively. Significantly higher volumes were recorded from the Gulf of Oman. The numerical abundance of zooplankton varied from 79 to 5098/m^3. Copepods comprised more than 50% of the zooplankton in over one-half of the collections from the Persian Gulf. Higher zooplankton volumes occurred in the Central Persian Gulf. There was no significant differences in the quantities of zooplankton between day and night. Fourteen species of pontellid copepods were identified in neuston samples from the Persian Gulf and Gulf of Oman, including 10 species that represent new records for the Persian Gulf. Information on tar balls are summarized in an Appendix to this report.

INTRODUCTION

Although connected to the northern Indian Ocean through the narrow Straits of Hormoz, the shallow Persian Gulf is surrounded by extensive hot and arid regions. Consequently, salinities and temperatures of the Gulf are unusually high for a marine area. The purpose of this study, which is based on plankton collections made in early spring, is to ascertain the major groups of plankton present, relative abundance and distribution within the Gulf, and whether species of certain taxa are indigenous to the Gulf or are a reflection of communities brought into the Persian Gulf from the Gulf of Oman through the Straits of Hormoz. Collections were also made at the surface for tar balls. This information is summarized in the Appendix.

METHODS

Samples were obtained in the Persian Gulf, from Bandar Abbas to just north of Bushehr, and from the northern portion of the Gulf of Oman on Cruise 93-18 of the R/V *ATLANTIS*, from 3-16 March 1977. Stations in the Persian Gulf were divided into three groups (Fig. 1), corresponding to the geographical regions shown by Emery (1956). Station locations and the types of collections at each station are summarized in Table 1.

Table 1. Station data and summary of samples analyzed.

Station No.	Position Lat.	Position Long.	Date 1977	Time hr.	Surface Temp. °C	Surface Salinity °/₀₀	Bottom Depth m	Plankton Phyto.[1]	Plankton Zoo.[2]
1	27°05'	56°17'		19	22.5	36.54			
2	26°06'	55°43'	3 III	03	23.0	36.89	87	S	
3	26°00'	55°17'	4 III	07	23.0	37.21	71	S	
4	26°23'	54°51'		12	23.0	36.87	49	S	O
5	25°47'	54°40'		14					N
6	26°01'	54°29'		20	23.5	36.07		S	N
7	25°47'	54°03'	5 III	03	23.0	38.79			N
8	26°06'	53°46'		08	23.0	37.62			N
9	26°33'	53°32'		15	23.0	37.44		S	N
10	26°02'	52°48'	6 III	03	21.5	39.62		S	
11	26°13'	52°43'		09	22.0	39.51			
12	26°43'	52°41'		15	22.0	38.93		S	
13	27°15'	52°34'		21	21.5	38.69		S	
14	26.56'	52°12'	7 III	03	20.5	39.51			
15	26°33'	51°52'		09	20.5	39.71		S	
16	26°59'	51°48'		15	21.0	39.44			
17	27°26'	51°43'		20	21.0	39.19		S	
18	27°03'	51°14'	8 III	03	20.0	39.44		S	
19	27°06'	50°53'		09	20.0	39.88			N
20	27°35'	50°46'		15	20.0	39.95			
21	27°59'	50°53'		21	20.0	39.46		S	
22	27°49'	50°28'		03	19.0	40.04			
23	27°37'	50°03'	9 III	09	19.5	40.57		S	N
24	28°05'	50°17'		15	20.0	40.40		S	N
25	28°25'	50°27'		21	20.0	39.67			N
26	28°40'	49°57'	10 III	03	20.0	40.46		S	N
27	28°39'	49°35'		08	19.0	40.48		S	N
28	29°10'	49°50'		15	20.0	40.51			N
29	29°20'	49°45'		22	19.5	40.48	31	S	N,O
30	29°03'	50°16'	11 III	03	19.0	40.38	44	S	N,O
31	28°47'	50°44'		06	19.0	39.83	29	S	N,O
32	28°29'	50°37'		10	20.0	39.66	53	S,P	N,O
33	27°57'	50°29'		15	20.0	39.85	59		N,O
34	27°27'	50°28'		20	19.0	40.34	59		N,O
35	27°12'	50°23'		22	20.0	40.20	60	S	N,O
36	27°04'	50°54'	12 III	03	20.5	39.91	63	S	N,O
37	27°01'	51°26'		07	21.0	38.09	70		N,O
38	26°58'	52°06'		12	22.0	38.94	52	S	N,O
39	26°55'	52°34'		19	22.5	38.62	72		N,O
40	26°31'	52°46'	13 III	00	22.5	37.79	75	S,P	N,O
41	25°63'	53°02'		04	22.0	39.45	67		N,O
42	25°39'	53°09'		08	22.0	39.45	44		N,O
43	25°32'	53°38'		11	23.0	38.75	42	S	N,O
44	25°20'	54°10'		15	23.5	37.62	29		N,O
45	26°06'	55°01'	14 III	00	23.5	37.27	84		N,O

Table 1 (continued)

Station No.	Position Lat.	Position Long.	Date 1977	Time hr.	Surface Temp. °C	Surface Salinity °/₀₀	Bottom Depth m	Plankton Phyto.[1]	Plankton Zoo.[2]
46	26°23'	56°04'	14 III	10	23.5	36.67	86		N,O
47	25°59'	56°47'		17	26.5	36.63	103	S,P	N,O
48	25°17'	56°58'		23	25.0	38.58	339		N,O
49	24°31'	57°33'	15 III	06	25.0	38.56	1654		N,O
50	24°24'	57°59'		12	24.5	38.54			N,O
51	26°04'	57°03'		23	24.0	36.54			
52	26°59'	56°32'	16 III	07	24.5	36.71			

[1] S=Surface; P=Depth Profile

[2] N=Neuston; O=Oblique Tow

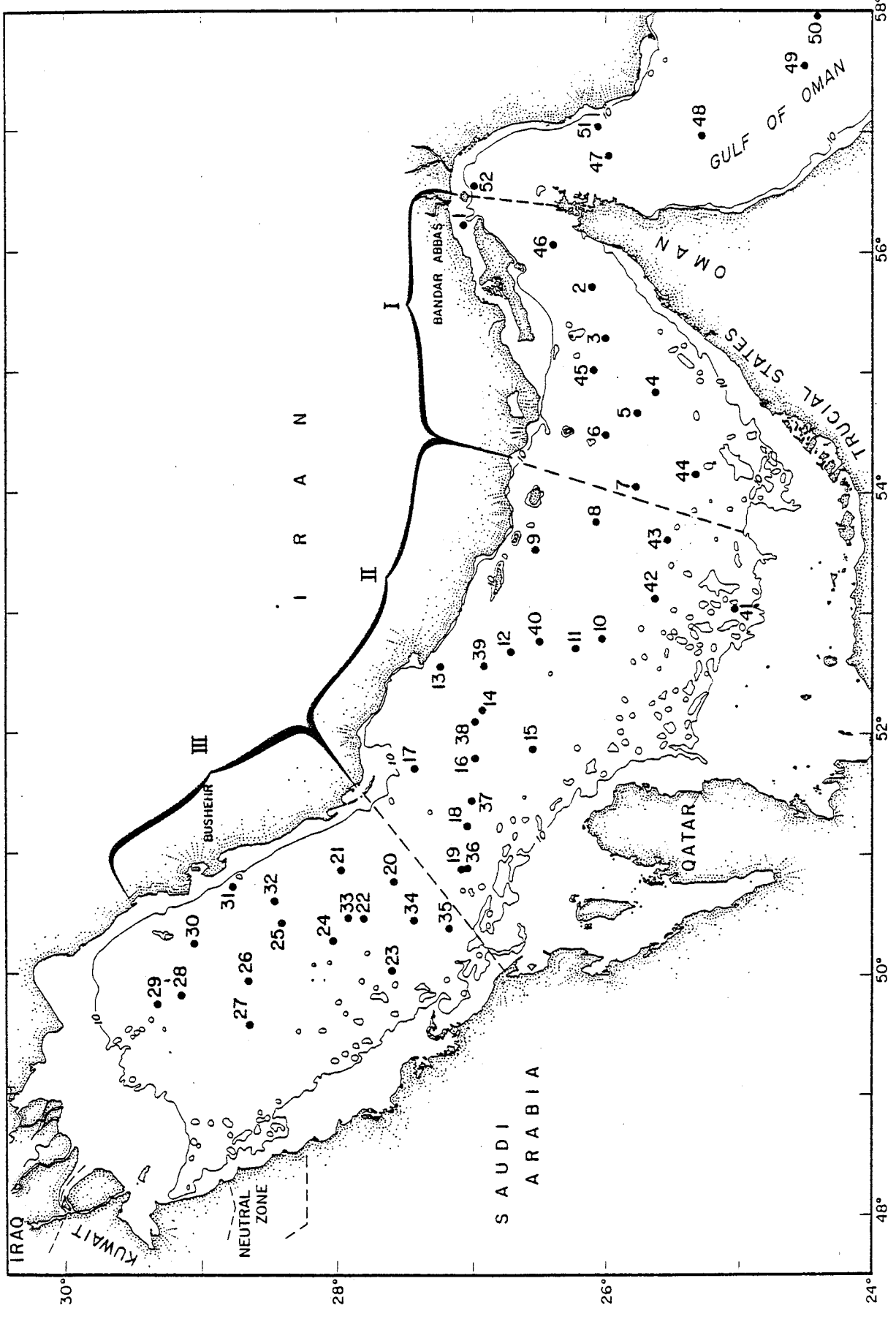

Figure 1. Station locations in the Persian Gulf and Gulf of Oman. The Persian Gulf is divided into three areas after Emery (1956).

Physical Measurements

Temperature and salinity were measured routinely at every station where biological collections were obtained, as well as at additional locations to provide a general view of conditions in the Gulf.

Surface temperatures were measured with a bucket thermometer and recorded to the nearest half degree Celsius. Several depth profiles were also made using Niskin bottles with attached reversing thermometers. A total of 69 measurements (51 surface and 18 depth) were made (Table 1).

Surface (bucket) and deep (Niskin bottle) samples were returned to Woods Hole for salinity determination by conductivity. A total of 51 samples were analyzed (Table 1).

Phytoplankton

Surface and deep water samples (250 ml) were collected and preserved with 2-3% sodium borate buffered formalin. In the laboratory, aliquots of these samples were centrifuged and the concentrated material transferred to a slide for examination with a compound microscope (Hulburt, 1976). Phytoplankton species were identified and enumerated and the counts converted to number of cells per liter of water for 31 collections (Table 2).

Zooplankton

Oblique Plankton Samples

Samples were collected with a 243 μm mesh plankton net with a

Table 2. Abundance of phytoplankton species in Persian Gulf and Gulf of Oman (no./l).

Station	2	3	4	6	9	10	12	13	15	17	18	21	23	24	26	27	29	30	31	32	32a	32b	35	38	40	40a	40b	43	47	47a	47b
Diatoms																															
Amphiprora sp.											15																				
Asteromophalus sp.														10																20	
Bacteriastrum delicatulum																												45			
Biddulphia mobiliensis																						60					30				
Chaetoceros affinis																										300					
C. denticula																						60									
C. didymus																										900					
C. lacinosus				215	150																										
C. peruvianus													15																		
C. spp.				430	120		150						30		30									510	2580	8100		90		200	
Climacodium frauenfeldiana													90	120	240	120	120	84													
Corethron hystrix												60																			
Coscinodiscus excentricus																											60			40	
C. marginatus																		12													
C. sp.										60																100	30				
Detonula moseleyana		300																													
Guinardia flaccida										40							20					40				13600	60				
Hemiaulus membranacea																	180		135												
Leptocylindrus danicus				2838			90		60		75				90									450	990		120	90			
L. minimus			180		135																										
Navicula membranacea		30		43																		200					60				20
N. splendida													15																		

Station	2	3	4	6	9	10	12	13	15	17	18	21	23	24	26	27	29	30	31	32	32[a]	32[b]	35	38	40	40[a]	40[b]	43	47	47[a]	47[b]
Diatoms, continued																															
Nitzschia braarudi				43																	30		120			100					
N. closterium	120	120	150	301	30		105	30	12	140	75	90	15								630	200		210	120	500	60	30			
N. delicatissima	330	135	11407	31304	105		105			80		600										40		240	330	600	30	45			
N. longissima			120		15																										
N. paradoxa																						340									
N. seriata		210		1806										30			180			20				120	450	2700	30	135			
N. sigma																20						20									
N. sp.																											30				
Pleurosigma angulatum									12	40			75								30	80					870				40
P. sp.										40			15	10								280					720				
Rhizosolenia alata		120		86	15	15	15	15		60			75	80										240	90			30			
R. alata f. *indica*														20	150		420	120	30			80									
R. bergonii																	80														
R. calcer avis																	120														
R. castracanei								15								100													675		
R. cochlea																						40									
R. hebetata																								30							
R. hyalina													15																		
R. imbricata v. *imbricata*															30																
R. imbricata v. *shrubsolei*																20	40							90				15			
R. robusta																	80														
R. setigera				86	15	15								10										60	180	100	30	30			
R. stolterfothii										150																					
Schroderella delicatula				258																						2500	30				
S. sp.										30																					

Station	2	3	4	6	9	10	12	13	15	17	18	21	23	24	26	27	29	30	31	32	32[a]	32[b]	35	38	40	40[a]	40[b]	43	47	47[a]	47[b]
Diatoms, continued																															
Skeletonema costatum				3827																				90	600	1500					
Stephanopyxis palmeriana																						940									
Surirella fastuosa																		12				20					60				
Thalassionema nitzschiodes				172						60			30			20				120		60		180							
Thalassiosira decipiens												30										40									
T. spp.																								120							
Thalassiothrix delicatula				172																				150	60						
T. frauenfeldii												90							30												
Unidentified centrics			900	2451									15									60					30				
Unidentified pennates	90	15	4730	172	15	45	15		24	80	45	210	45	50						20	60	200	150	120	60	1300	990	15	15		80
Dinoflagellates																															
Amphidinium sp.																								30							
Ceratium furca						15	30									60	20														
C. fusus													30				20	24	15	20			15								
C. lineatum																			30												
C. macroceros																			30	20											
C. pulchellum																20	20														
C. teres															30						30										
C. trichoceros																			15												

Station	2	3	4	6	9	10	12	13	15	17	18	21	23	24	26	27	29	30	31	32	32[a]	32[b]	35	38	40	40[a]	40[b]	43	47	47[a]	47[b]
Dinoflagellates, continued																															
Gymnodinium punctatum		15						15							30			24		20	30										
Gyrodinium sp.																							15								
Katodinium rotundatum	30							15																							
Noctiluca miliaris				43	15		15																					60			
Oxytoxum cucumis		15				45		30		40	30	60	15						15												
O. laticeps								15	24		15									40					30						
O. tesselatum						45	15	60	48		30																				
O. scolopax										20										20					30						
O. variabile	30		240			60	15	45	24	20	150	120		10		20	20			100	180	40	120	120		100		75			
O. sp.								15																							
Peridinium depressum																										100					
P. globules																	20														
P. trochoideum								15										12						30	30						
Podolampas palmipes																												15			
Porella perforata			30						24								20				30										
Pronoctiluca pelagica			30																												
P. phaeocystoides		15																													
Prorocentrum gracile																			15												
P. lebourae																												30			
P. micans				43										10																	
P. cf *micans*																													15		
P. obtusidens			480									30		10		20							15		30						
Unidentified dinoflagellates		75		135	135	75		60	12	60	60	60				20	20			40	30		30		60			15	15	20

Station	2	3	4	6	9	10	12	13	15	17	18	21	23	24	26	27	29	30	31	32	32[a]	32[b]	35	38	40	40[a]	40[b]	43	47	47[a]	47[b]
Coccolithophores																															
Acanthoica acanthifera																				20											
Anoplosolenia brasiliensis																			15	60				30	30						
Anthosphaera oryza										60	15																				
Braarudosphaera bigelowi													15		30																
Calciosolenia murrayi					195			15	12	40	105	180	45	160			40			660	3270	320	195	270	30		60				
Coccolithus huxleyi	180	135	300	43	900	270	465	315	144	240	285	990					60			820	570	80	15	1320	210	2400		255		80	
Gephyrocapsa oceanica	5790	600	2370	1161	945	210	900	2070	684	1440	945	1800	300	280	120		1260	696	15	1760	1470	500	510	290	90	3600	90	255		60	240
Ophiaster hydroidea			30		15							30										40									
Umbilosphaera hulburtiana																												15			
Unidentified coccoliths																								60							
Cryptomonads																															
Chilomonas marinas		15	60			60		30		20	45	150		30	90	20		24	30	260	120		285	120	60				20		

Station	2	3	4	6	9	10	12	13	15	17	18	21	23	24	26	27	29	30	31	32	32[a]	32[b]	35	38	40	40[a]	40[b]	43	47	47[a]	47[b]
Other Groups																															
Euglenoids			120	86	30																	20									
Tintinnids													15												100						
Trichodesmium filaments															5070	19380	40	768	165												
Silicoflagellates																					30										
Ciliates		15	120		75						15	30								60			30						45		
Flagellates			240																												
Unidentified	420	390	720	258	30	30	165	90	24	120	60			30	90	80		12	15	80	30		75	870	120	3200		15	165		20
Total	6960	2235	22227	45973	2940	885	2085	2850	1104	2660	2145	4530	855	860	6000	19900	2800	1788	555	4140	6480	3760	1575	5750	6180	41800	3390	1260	930	200	640

[a]Sample taken halfway between surface and bottom.

[b]Sample taken just above bottom.

diameter of 70 cm. A digital flowmeter (General Oceanics Model 2030) was mounted in the mouth of the net to permit calculation of the amount of water filtered for each tow. At shallow stations within the Persian Gulf proper, oblique tows were made from the surface to approximately five meters above the bottom. At deeper locations in the Gulf of Oman (depth greater than 100 m) tows were made from a standard depth of 60 m. Zooplankton was preserved with 5% sodium borate buffered formalin. Biomass and taxonomic composition determinations were subsequently carried out for each of the 23 samples.

Displacement volumes for biomass measurements were determined after removal of larger organisms (medusae, salps, fish) by placing the samples in a graduated cylinder and recording the volume. The sample was then poured into a second cylinder through a net (243 μm) to retain the plankton. After the sample had been allowed to drain for a specified length of time to remove excess liquid, the volume of water collected in the second cylinder was recorded. The difference between the two cylinder readings represents the displacement volume (in cc) of the plankton. This value was divided by the amount of water filtered for that tow, to give the plankton biomass/m^3 at each station.

Subsamples for determination of taxonomic composition of the zooplankton were obtained with a Folsom plankton splitter (McEwan, Johnson and Folsom, 1954), such that approximately 200 copepods (usually the most abundant group) were counted for each sample. Zooplankton was identified with the aid of a dissecting microscope and enumerated according

to taxonomic group: copepoda, cladocera, chaetognatha, larvacea, etc.

Neuston Samples

Samples were collected from the sea surface with a one-meter diameter, 333 μm mesh net mounted on a rectangular fiberglass frame. This "neuston" net is a modification of the stainless steel sampler described by Bartlett and Haedrich (1968). The net was typically towed at two to three knots for 15 to 30 minutes. Duration of the tow was dependent upon the surface concentration of organisms such as jellyfish medusae, salps and siphonophores which, when excessively abundant, clogged the meshes of the net. Samples were preserved with 5% sodium borate buffered formalin. Pontellid copepods were individually removed from the 34 neuston samples.

RESULTS

Phytoplankton

Approximately 100 taxa of phytoplankton (diatoms, dinoflagellates, coccolithophores and other groups) were recognized in collections from the Persian Gulf and Gulf of Oman (Table 2). They ranged in abundance from 555 to 45,973 cells/l in surface samples, and from 200 to 41,800 cells/l in deeper samples.

Of the major groups, diatoms were the most important in terms of number of species found (55) and total abundance over all stations.

Coccolithophores were represented by fewer species (9) and lower abundance, but were probably the most significant overall group because of their frequency of occurrence and tendency to be the dominant organism at the majority of stations. Dinoflagellates as a group were rather insignificant. Although a fairly large number of species were encountered (30) their total abundance was low and their occurrence sporadic. One species, *Oxytoxum variabile,* did have a widespread distribution, occurring at 61% of the stations, but never achieved significant abundance. This genus was also represented by five other species.

Only five species of phytoplankton occurred at 50% or more of the stations sampled: *Gephyrocapsa oceanica, Coccolithus huxleyi, Calciosolenia murrayi* (coccolithophores); *Nitzschia closterium* (diatom); and *Oxytoxum variabile* (dinoflagellate). Coccolithophores were dominant at 20 stations, diatoms at seven, and filaments of the blue-green alga *Trichodesmium* at the remaining four.

Although it occurred at less than half of the stations, the diatom *Nitzschia delicatissima* was the most abundant species (up to 31,304 cells/l at one station). *G. oceanica* was second in abundance and although it never reached more than 5,790 cells/l at any one station, this low abundance was offset by its frequency of occurrence (at 94% of the stations). The next most abundant species were *Trichodesmium, Guinardia flaccida, Chaetoceros* sp. and *C. huxleyi.*

Distribution of Important Species

G. oceanica - This species was distributed throughout the region sampled. It was absent from only two stations, one in the upper portion of the Persian Gulf (above Bushehr), and one in the Gulf of Oman. *G. oceanica* was the most dominant and pervasive phytoplankton species encountered.

C. huxleyi - This species was present at all stations in the central and lower part of the Persian Gulf, but it was less common in the upper region.

C. murrayi - This species was most common in the central area of the Persian Gulf. It was not found in the upper and lower regions.

N. delicatissima - This was the dominant species at two stations in the lower Gulf. Elsewhere it was common except in the upper region.

N. closterium - The distribution of this species was similar to that of *N. delicatissima*.

Chaetoceros sp. - This species was patchily distributed throughout the Persian Gulf.

G. flaccida - This species was sparsely distributed along the northern side of the lower and central regions.

O. variabile - A common but never abundant species throughout the Persian Gulf.

Trichodesmium filaments - This species was present at four stations at the head of the Persian Gulf. However, it was the most abundant alga at each station where it was observed.

Comparison of the Three Areas (Fig. 1)

Coccolithophores were moderately abundant throughout the entire region, but no blooms were observed. Diatoms were less abundant, but blooms did occur in one area of the lower Persian Gulf. Both groups occurred in low concentrations in the upper region of the Persian Gulf (Area III), where there was a bloom of the blue-green alga *Trichodesmium*.

The central portion of the Persian Gulf, Area II, was relatively homogeneous, with low concentrations of diatoms and medium abundances of coccolithophores, which were always numerically the dominant species.

Phytoplankton in the lower Persian Gulf, Area I, was more diverse, with blooms of diatoms at two stations.

Only one location in the Gulf of Oman was sampled for phytoplankton, and this station was dominated by a diatom, *Rhizosolenia castracanei*, which was encountered at no other station. This location had low concentrations of both diatoms and coccolithophores, and the smallest number of species recorded in any sample.

Vertical Distribution

Subsurface samples were taken at three locations: the upper Persian Gulf (Station 32), the mid-region of the Persian Gulf (Station 40), and the Gulf of Oman, just south of the Straits of Hormoz (Station 47). In addition to the standard surface samples, collections were made just above the bottom, and midway between surface and bottom. Analysis of these collections showed that the number of diatom species increased

from surface to bottom, while the numbers of coccolithophore and dinoflagellate species were highest at the surface and decreased with depth. No consistent trends were evident in phytoplankton concentration, however. In general, species composition of the deeper samples was not noticeably different than at the surface. One exception was observed at the mid-depth sample from Station 32, where *Stephanopyxis palmeriana* was the most abundant species. This diatom was not found in any other sample.

Zooplankton

Oblique Plankton Samples

The biomass of the zooplankton varied from .11 - 2.00 cc/m^3 and .52 - 2.27 cc/m^3 in the Persian Gulf and Gulf of Oman respectively (Table 3). Gulf of Oman biomass values were found to be significantly different from those in the Persian Gulf, as shown by the Mann-Whitney test (Zarr, 1974), with higher values occurring in the Gulf of Oman. Test data are given in Table 4.

The numerical abundance of zooplankton in the Persian Gulf ranged from 79 - 5098/m^3. Copepods were the most abundant taxon (Table 5) comprising greater than 50% of the zooplankton in 14 of the 20 collections. Ostracods were the second most abundant taxon, followed by doliolids, larvaceans, cladocerans and chaetognaths. Copepods were numerically also the most abundant taxon in the Gulf of Oman, followed by doliolids, larvaceans, cladocerans, chaetognaths

Table 3. Zooplankton biomass in Persian Gulf and Gulf of Oman.

Region	Station No.	Biomass[1] cc/m^3	cc/m^2
Persian Gulf[2]			
I	29	1.11	34.41
	30	0.35	15.40
	31	0.53	15.37
	32	0.22	11.66
	33	0.33	19.47
	34	0.35	20.65
	35	0.31	18.60
II	36	0.31	19.53
	37	0.69	48.30
	38	0.88	45.76
	39	0.40	28.80
	40	1.28	96.00
	41	1.48	99.16
III	42	2.00	88.00
	43	0.56	23.52
	44	0.31	8.99
	45	0.30	25.20
	46	0.26	22.36
	3	0.11	7.81
	4	0.95	46.55
Gulf of Oman[3]	47	2.27	136.20
	48	0.52	31.20
	49	1.48	88.80
	50	0.58	34.80

[1] Displacement volumes excluding jellyfish and other large animals.

[2] Tows made from surface to near bottom.

[3] Tows made from surface to 60 m.

Table 4. Comparison of zooplankton biomass and numerical abundance between day and night samples in the Persian Gulf, and between all samples in the Persian Gulf and all samples in the Gulf of Oman. Samples are ranked and compared by the Mann-Whitney Test.

Station	Biomass (cc/m^3)	Total Zoo. (no/m^3)	Rank: Day vs Night Biomass	Rank: Day vs Night Total Zoo.	Rank: Persian Gulf vs Gulf of Oman Biomass	Rank: Persian Gulf vs Gulf of Oman Total Zoo.
			Persian Gulf - Day Samples			
3	.11	79	1	1	1	1
4	.95	2422	16	17	18	20
31	.53	3675	12	19	13	23
32	.22	415	2	2	2	2
33	.33	482	8	3	8	3
37	.69	1786	14	13	16	15
38	.88	1849	15	14	17	16
39	.40	1329	11	8	11	10
42	2.00	1424	20	9	23	11
43	.56	2734	13	18	14	21
44	.31	2056	5.3	15	5.3	17
46	.26	1020	3	5	3	7
			Persian Gulf - Night Samples			
29	1.11	1710	17	12	19	14
30	.35	2394	9.5	16	9.5	19
34	.35	601	9.5	4	9.5	4
35	.31	1232	5.3	7	5.3	9
36	.31	1107	5.3	6	5.3	8
40	1.28	1561	18	10	20	12
41	1.48	5098	19	20	21.5	24
45	.30	1640	4	11	4	13
			Gulf of Oman - Day and Night Samples			
47	2.27	2159			24	18
48	.52	978			12	5
49	1.48	2809			21.5	22
50	.58	982			15	6
		U =	53	50.5	64.6	41
			NS	NS	*	NS

NS = $P > .10$
* = $P \leq .10$

Table 5. Abundance of zooplankton taxa in Persian Gulf and Gulf of Oman (no./m^3).

Station No.	3	4	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
CRUSTACEA																								
Copepoda	32	1601	994	1849	2494	280	255	442	744	600	1242	1322	614	613	1884	568	870	558	748	636	959	860	1775	205
Cladocera		8	210	9	557	2	1		14					26	122	367	457	40	33		160	4	149	5
Ostracoda	29	49	307	114	359	1	49	90	307	305	181	232	465	543	1762	158	919	1234	640	8	12	4	14	
Amphipoda	1	8	23	19		1	1				9	14		9	8			7	7		11		57	1
Euphausiacea								4																
Decapoda				19			2	1	34	10				2		13		7	7					
Mysidacea				5																				
CRUSTACEAN LARVAE																								
Copepod nauplii		16	6	9		2									8	2		4					7	
Decapod zoeae		8		5							4				8	2	5	4						
Stomatopod larvae																36								
Euphausiid larvae	<1				9	7	1	9	10	26	9	42	15	16	23	6	25	29	30	286	50	4	28	
Barnacle nauplii									2	3				7										
Megalopae									2					5										
Decapod larvae									2				3			2	10	7	26	5	6			
OTHER GROUPS																								
Chaetognatha	1	16	17	142	123	3	10	4	14	20	43	14	15	19	106	38	49	4	22	44	96	39	92	26
Polychaeta			11	19	9	3	1	3	5	3	17	7	8	9	30	8	15	7	4	3	26	4	7	4
Pelecypoda			17	52	19	14	9	23	14	7	9	56	20	14	304	23	128	7	70		25		21	
Gastropoda	<1	8	34	14		3	3	7	19	3	9		10	12	76	30	25	29	15	19	28	39	28	5
Larvacea	5	545	40	33	76	2	6	1	2	13	86	56	13	178	524	76	49	90	30	11	482		291	636
Doliolidae	8	130	28	19		84	126	9	56	98	129	106	146	14	30	13		4	7		30	12	71	13
Siphonophora	1		11	81	19	14	14	4	7	16	35		15	5	30	23		11			2			
Salpidae							3				13													
Holothurian		8														6	10							
Cyphanautes				5				1																
Larval larvacean								3		3				19										
FISH																								
Eggs		24	6		9		1						5	7							36	8	106	40
Larvae			6												8						2		28	
TOTAL	79	2421	1710	2394	3674	416	482	601	1232	1107	1786	1849	1329	1565	5098	1424	2734	2056	1650	1020	2159	978	2809	982

and siphonophores.

Day and night comparisons were made on the biomass and numerical abundance of zooplankton in the Persian Gulf. No significant difference was found in either biomass or density (Mann-Whitney test, Table 4).

The three regions (Fig. 1) of the Persian Gulf recognized by Emery (1956) were compared in terms of total zooplankton biomass and numerical abundance of the six most abundant taxa listed above. On the basis of the Kruskal-Wallace test (Zarr, 1974) there was a significant difference in zooplankton biomass among samples from the three regions, with the highest values occurring in the central region (Area II). A significant difference in regional abundance was evident for only one of the six taxonomic groups tested: the population density of the doliolids was appreciably higher in the central region than in the upper or lower portions of the Persian Gulf. Test data is given in Table 6.

Neuston Samples

A total of 14 species of pontellid copepods (Table 7) were identified in the 30 neuston samples from the Persian Gulf and four samples from the Gulf of Oman. All 14 species were recorded from the Persian Gulf, but only five species appeared in the Gulf of Oman samples. The fact that fewer species were recorded in the Gulf of Oman is not entirely related to the relatively few samples obtained there, since several common species were absent or poorly represented

Table 6. Comparison of zooplankton abundance in three regions of the Persian Gulf in March, 1977. Samples are ranked and compared by the Kruskal-Wallace Test.

Region	Station	Biomass (cc/m^3) Value	Rank	Total Zoo. (no/m^3) Value	Rank	Copepods (no/m^3) Value	Rank	Ostracods (no/m^3) Value	Rank	Chaetognaths (no/m^3) Value	Rank	Larvaceans (no/m^3) Value	Rank	Doliolids (no/m^3) Value	Rank	Cladocerans (no/m^3) Value	Rank
I	3	.11	1	79	1	32	1	29	3	1	1	5	4	8	2	0	
	4	.95	16	2422	17	1601	17	49	4.5	16	9	545	20	130	17	8	3
	43	.56	13	2743	18	870	13	919	18	49	17	172	18	49	8	457	12
	44	.31	5.3	2056	15	558	5	1234	19	4	3.5	14	10	90	12	40	8
	45	.30	4	1640	11	748	12	640	17	22	13	11	7	30	7	33	7
	46	.26	3	1020	5	636	10	8	2	44	16	8	6	11	4	0	
II	36	.31	5.3	1107	6	600	7	305	11	20	12	13	8.5	98	13	0	
	37	.69	14	1786	13	1242	15	181	9	43	15	86	17	129	15	0	
	38	.88	15	1849	14	1322	16	232	10	14	6.5	56	14	106	14	0	
	39	.40	11	1329	8	614	8.5	465	15	15	8	13	8.5	146	18	0	
	40	1.28	18	1561	10	614	8.5	544	16	19	11	68	15	178	19	26	6
	41	1.48	19	5098	20	1884	19	1762	20	106	18	175	19	524	20	122	9
	42	2.00	20	1424	9	568	6	158	8	38	14	53	13	76	10	367	11
III	29	1.11	17	1710	12	994	14	307	12.5	17	10	40	12	28	6	210	10
	30	.35	9.5	2394	16	1849	18	114	7	142	20	33	11	19	5	9	4
	31	.53	12	3675	19	2494	20	359	14	123	19	76	16	0	1	557	13
	32	.22	2	415	2	280	3	1	1	3	2	2	2.5	84	11	2	2
	33	.33	8	482	3	255	2	49	4.5	10	5	6	5	126	16	1	1
	34	.35	9.5	601	4	442	4	90	6	4	3.5	1	1	9	3	0	
	35	.31	5.3	1232	7	744	11	307	12.5	14	6.5	2	2.5	56	9	14	5
		H = 4.66 *		H = 0.75 NS		H = 0.35 NS		H = 2.09 NS		H = 0.84 NS		H = 4.22 NS		H = 8.10 **		H = 1.10 NS	

NS = P > .10
* = P ≤ .10
** = P ≤ .05

Table 7. Occurrence of copepods of family Pontellidae in neuston samples from Persian Gulf and Gulf of Oman. (For each species first number represents number of females, second number represents males from approximately the first 100 preadult and adult pontellids removed from subsamples.)*1

Species	Station Number																
	5	6	7	8	9	19	23*2,3	24*3	25	26*3	28*3	29	30	31	32*3	34	35*3
							PERSIAN GULF										
Calanopia elliptica		1,1				15,6							5,3			9,5	5,5
Labidocera acuta	2,26	1,50	0,3	14,26	1,14	1,2								1,0			
L. detruncata																	
L. kroyeri	1,0	1,2				10,3			3,0	2,0		0,19	10,10			3,27	3,1
L. minuta	0,36	0,1	1,1	0,9	0,27	2,4				1,4	1,0	7,24	11,13	1,0		0,1	
L. pavo			1,0														
L. sp.				1,0													
Pontella karachiensis	2,2		12,21	8,20	19,17	2,1	5,11	2,3	1,1	0,2	11,15		5,9	1,0	3,3	5,4	1,3
P. securifer			0,1	8,7	0,3										0,3		
P. spinipes					1,0										1,0		
Pontellina plumata																	
Pontellopsis herdmani	9,31	12,14	1,1	10,1	4,6	11,32			2,0	2,6	1,0	3,24	7,34	17,75		0,7	2,3
P. krameri																	
P. regalis?																	
No. Specimens	109	83	42	104	92	89	16	5	7	17	28	77	107	95	10	61	23
No. Species	5	5	6	6	6	6	1	1	3	4	3	3	5	4	3	5	4

*1 Preadults not identified or recorded.

*2 Sample composed mostly of salps and/or jellyfish.

*3 Pontellids from entire sample removed. Samples 27 and 33 contained no pontellids, mostly salps.

Table 7. Continued

Species	Station Number														
	36	37*3	38	39	40	41	42*2,3	43	44	45	46	47	48	49	50*3
	PERSIAN GULF											GULF OF OMAN			
Calanopia elliptica	25,15			1,1	3,0	2,0				8,5					
Labidocera acuta	0,1		0,1	0,1	3,28	0,4	0,1	0,1	8,53	0,16	3,5	40,67	11,38	42,49	7,15
L. detruncata										1,0					2,0
L. kroyeri	1,0			2,4		1,0				1,1					
L. minuta	1,1		1,3	1,0	6,4	25,42		1,11	0,2	8,7	4,5	0,1			0,1
L. pavo															
L. sp.			0,1?	1,0											
Pontella karachiensis	2,7	12,7	1,1	1,0	2,3	1,2	4,4	4,10	13,15	4,2	11,22				
P. securifer		0,1	0,1	3,3	3,6	1,1									
P. spinipes		1,0													
Pontellina plumata										0,2			0,17	0,1	0,1
Pontellopsis herdmani		0,2	14,65	8,45	8,31	2,6		38,32	5,7	0,5					
P. krameri			3,2	4,16	1,3	0,1		2,3		0,1	9,13		14,19	4,12	
P. regalis?					0,2										
No. specimens	53	23	93	91	103	88	9	102	103	61	72	108	99	108	26
No Species	5	4	7	9	8	8	2	5	4	9	4	2	3	3	4

*1 Preadults not identified or recorded

*2 Sample composed mostly of salps and/or jellyfish.

*3 Pontellids from entire sample removed. Samples 27 and 33 contained no pontellids, mostly salps.

in the Gulf of Oman. Two species, *Pontellopsis herdmani* and *Pontella karachiensis,* occurred in more than 22 of the 30 samples from the Persian Gulf, but were absent from the Gulf of Oman. *Calanopia elliptica* and *Labidocera kroyeri* were found in more than 10 Persian Gulf samples and represented in these by more than 100 specimens, but both were absent from Gulf of Oman collections. Moreover, one other species, *Labidocera minuta,* was represented in 21 of the Persian Gulf samples by 266 specimens but by only two specimens in two samples from the Gulf of Oman (Table 8). *Labidocera acuta* was the most typical Gulf of Oman species. It also occurred regularly in the Persian Gulf. On the basis of the above described distributions it appears that the Persian Gulf maintains an indigenous and diverse pontellid fauna.

One species occurring in the Persian Gulf exhibited a somewhat restricted distribution. *Pontellopsis krameri* was found only in the southern half of the Persian Gulf and Gulf of Oman. It appears that it is recruited from the Gulf of Oman and may not maintain a population within the Persian Gulf. Its congener, *P. herdmani,* was very common in the Persian Gulf, but absent from the Gulf of Oman.

DISCUSSION

Phytoplankton

The dominance of coccolithophores in the Persian Gulf can probably be explained by an analysis of their kinetic characteristics. Species

Table 8. Pontellid copepods identified in 34 neuston samples obtained from Persian Gulf and Gulf of Oman.

	Frequency	
	Persian Gulf (30 samples)	Gulf of Oman (4 samples)
Calanopia elliptica (Dana)	10	0
Labidocera acuta (Dana)	17	4
L. detruncata (Dana)[1]	1	1
L. kroyeri (Brady)[1]	13	0
L. minuta Giesbrecht	20	3
L. pavo Giesbrecht[1]	1	0
L. sp.	3	0
Pontella karachiensis Rehman[1]	26	0
P. securifer Brady[1]	9	0
P. spinipes Giesbrecht[1]	3	0
Pontellina plumata (Dana)[1]	1	3
Pontellopsis herdmani Thompson and Scott[1]	22	0
P. krameri (Giesbrecht)[1]	6	3
P. regalis (Dana)?[1]	1	0

[1] New record for Persian Gulf.

such as those found in the Persian Gulf particularly *Coccolithus huxleyi*, possess the ability to survive at low concentrations of nutrients. According to Eppley *et al.* (1969), *C. huxleyi* has the lowest K_s determined for any species. K_s is the concentration of nutrient at which half the maximum uptake rate occurs. *C. huxleyi* has a K_s of 0.1 µg-at. N/l, as compared to a range of 0.5 - 5.5 µg-at. N/l for diatom species. Although this species occurs ubiquitously between 40°N and 40°S in the deep ocean, it is most abundant in upwelling areas, demonstrating that it has the ability to respond to more enriched conditions. In the Persian Gulf, as in most oceanic areas, the coccolithophores are widely distributed, though not particularly abundant, because they are able to maintain themselves, if not to flourish, at concentrations of nutrients too low for most other types of phytoplankton. It has been shown (Brewer, personal communication) that nitrate concentrations in the Persian Gulf are very low at this time of year.

Growth rate is another factor which can influence phytoplankton distribution. *C. huxleyi* has a maximum growth rate of 1.85 doublings per day, which is similar to the rate determined for diatom species (Eppley and Sloan, 1966). This rapid reproductive rate ensures that this species will be able to take maximum advantage of favorable nutrient conditions. *C. huxleyi* is moderately abundant (greater than 1,000 cells/l) at one station in the Persian Gulf. *Gephyrocapsa oceanica* is moderately abundant at 10 stations, implying

that it has an even greater growth potential than *C. huxleyi*.

Diatoms have a combination of a high K_s and a rapid growth rate. The requirement for good nutrient conditions is reflected by the fact that no species of diatom occurs at as many stations in the Persian Gulf as the two coccolithophores *G. oceanica* and *C. huxleyi*. The high maximum growth rate is illustrated by the very high abundance (greater than 10,000 cells/l) of *Nitzschia delicatissima* at two stations in the lower Persian Gulf. It appears that nutrient concentrations were higher in this area and this species was able to take advantage of the situation by its capacity for rapid reproduction. Brewer (personal communication) has shown that surface values of nutrients are high in the Gulf of Oman due to monsoonal upwelling. The bloom of diatoms in Area I may reflect the influx of richer surface water through the Straits of Hormoz to the Persian Gulf.

Some dinoflagellate species, notably those of the genus *Oxytoxum*, are found in the Persian Gulf, but they are never abundant. This may be attributed to their low K_s coupled with a low growth rate. This paucity of dinoflagellate flora is in contrast to the situation in the Red Sea, another shallow arm of the Indian Ocean, where Kimor (1973) has reported the dominance of dinoflagellates over diatoms. Böhm (1931) observed a reduction in the number of dinoflagellate species in the Persian Gulf and Gulf of Oman, compared to the Arabian Sea.

Zooplankton

Zooplankton biomass and distribution in the Persian Gulf

The observations made in the Persian Gulf in March apparently coincided with a period of considerable biological activity there. Extensive shoals of juvenile fish, jellyfish, salps and doliolids were usually present and captured in large numbers in the neuston and zooplankton nets. Considerable diversity of crustacean larvae and the reproductive stages of other invertebrates were represented in most samples.

Our results indicate that zooplankton distribution throughout the Persian Gulf is relatively homogeneous - at least in spring. Elevated biomass values in the central portion of the Gulf were traced to high local concentrations of doliolids, while other major taxonomic groups exhibited no significant geographical variation in patterns of abundance.

Of the 14 species of pontellid copepods recognized in the neuston samples, nine were present only in the Persian Gulf. Although five species occurred in the Gulf of Oman, these were also present in the Persian Gulf. The nine Persian Gulf species represent six genera. Two of the species (*Pontella karachiensis, Pontellopsis herdmani*) were widely distributed. With the exception of *Pontellopsis krameri,* which appears to be recruited from the Gulf of Oman, no obvious distribution pattern was evident for the other species in the Persian Gulf.

Ten species of pontellids found in this study have not previously been reported from the Persian Gulf (Table 5). Ten species of pontellids have been reported from the Red Sea, including six species that are common to both areas.

Comparison of zooplankton abundance with other regions.

Although few zooplankton biomass data are available for the Gulf of Oman, the present data represent the first such measurements for the Persian Gulf. It has already been pointed out that the zooplankton stock of the Gulf of Oman was signficantly higher than that of the Persian Gulf.

Previous measurements of zooplankton biomass in the Gulf of Oman were reported by Lenz (1973) whose two values (in winter) were 13 and 20 mg/m^3 dry weight. Assuming that dry weight is equivalent to about 10% of the displacement weight, these values can be compared to the range of our four Gulf of Oman measurements, which when converted to dry weight, varied from 52 to 227 mg/m^3 (60 m water column). Rao (1973) showed that zooplankton displacement volumes ranged from 20 to 39.9 ml/m^2 (200 m water column) during November in the Gulf of Oman. These latter two values may be compared to our range of 31.2 to 136.2 cc/m^2 during March. Thus it appears that the standing stock of zooplankton in the Gulf of Oman in spring is higher than in winter. Further to the east outer coastal and off shore water of Pakistan (Haq *et al.*, 1973) zooplankton displacement volumes ranged from approximately 50 to 100 ml/m^2, excluding a high value of 405 ml/m^2. These values are comparable to our Gulf of Oman values but generally

higher than the Persian Gulf. If only Haq's near shore samples are included (mean = 26 ml/m^2, range = 5-65 ml/m^2) our biomass measurements for the Persian Gulf (mean = 34 cc/m^2, range = 8-99 cc/m^2) are comparable to, but somewhat higher than, those from inshore Pakistanian waters.

SUMMARY

1. Over 100 different types of phytoplankton were identified in samples from the Persian Gulf and Gulf of Oman.

2. Coccolithophores, primarily *Gephyrocapsa oceanica* and *Coccolithus huxleyi*, were the most significant component of the phytoplankton. Diatom assemblages were generally characterized by high diversity and low abundance. Dinoflagellate species were neither abundant nor widely distributed.

3. Zooplankton was homogeneous throughout the Persian Gulf, except for the presence of relatively high concentrations of doliolids in the central area.

4. Large numbers of juvenile fish, jellyfish and salps were observed.

5. Copepods were the dominant constituent of the zooplankton, followed by ostracods. Other major groups included doliolids, larvaceans, cladocerans, chaetognaths and siphonophores.

6. Fourteen species of pontellid copepods were identified from the neuston, including 10 species not previously reported from the Persian Gulf, and eight species not recorded from the Red Sea.

7. Three pontellid species, *Pontella karachiensis*, *Pontella herdmani*, and *Labidocera acuta* were widely distributed throughout the Persian Gulf.

8. Zooplankton in the Gulf of Oman was distinguished from the Persian Gulf by its high biomass, relatively impoverished neustonic community, and comparatively insignificant population of ostracods.

9. Biomass measurements were generally comparable to reported values for other inshore areas of the Indian Ocean.

10. Fourteen collections were made for tar balls.

ACKNOWLEDGEMENTS

We wish to thank Dr. Edward M. Hulburt for analysis of the phytoplankton samples, and Mr. Stephen Graham for competent assistance in the laboratory. Subsurface phytoplankton samples were collected with the aid of Mr. Jeffrey Ellis. We also wish to thank Dr. David Ross for his efforts in making our participation in the Persian Gulf cruise possible.

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APPENDIX

As part of a comprehensive study, 14 collections were made for tar balls in the Persian Gulf and Gulf of Oman. Floating tar was observed at some stations. Dr. James Butler of Harvard University is performing physical and chemical analyses to provide a quantitative measurement of the tar collected from each tow.

Collection data is summarized below.

Sample #	Width of Net cm	Distance Towed km	Date			Time		Quad.	Lat.		Long.		Wind		Wave		Temp. °C	
			day	mon	yr	hr	min		Deg	Min	Deg	Min	Direction	Speed kts	Period sec	Height	Air	H_2O
16	40	1.4	15	02	77	11	36	1	24	15	59	28	36°	4		2	24.4	23.0
17	40	.2	17	02	77	07	10	1	23	49	50	37	--	0	0	0	26.8	21.8
18	40	1.0	04	03	77	13	14	1	25	53	54	37	--	0	0	0	33.3	23.2
19	40	1.4	06	03	77	17	12	1	27	07	52	35	290°	5			20.0	22.1
20	40	1.5	09	03	77	06	00	1	27	55	50	43	Retrieved from Bio Sample					
21	40	1.5	09	03	77	13	12	1	28	14	52	43	315°	2	3	2	21.5	20.0
22	40	1.7	10	03	77	12	34	1	29	13	49	53	225°	1	0	0	21.1	19.0
23	40	---	11	03	77	16	00	1	27	46	50	29	Retrieved from Bio Sample					
24	40	1.1	12	03	77	16	05	1	26	54	52	33	270°	3	3	3	21.1	20.5
25		1.2	13	03	77	12	00	1	25	23	54	17	045	1	0	0	26.6	23.6
26	40	1.2	15	03	77	08	13	1	24	25	57	56	290°	1	11	1	27.7	24.2
27	100	1.3	18	03	77	07	27	1	24	25	57	23	225°	2	0	0	25.3	24.5
28	100	1.3	19	03	77	12	09	1	25	10	58	33	10°	1-2	2	1	28.8	26.2
29	100	1.2	20	03	77	15	15	1	23	51	59	17		0	1	0	28.8	27.5

BIBLIOGRAPHIC DATA SHEET	1. Report No. WHOI-78-38	2.	3. Recipient's Accession No.

4. Title and Subtitle

REPORT B: GENERAL BIOLOGICAL OCEANOGRAPHIC DATA FROM THE PERSIAN GULF AND GULF OF OMAN

5. Report Date: May 1978

6.

7. Author(s)

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8. Performing Organization Rept. No.

9. Performing Organization Name and Address

Woods Hole Oceanographic Institution
Woods Hole, MA 02543

10. Project/Task/Work Unit No.

11. Contract/Grant No.

12. Sponsoring Organization Name and Address

Iranian Department of the Environment

13. Type of Report & Period Covered

Technical

14.

15. Supplementary Notes

16. Abstracts

Quantitative phytoplankton (31 samples) and zooplankton (23 samples) collections were made throughout the Persian Gulf and at several places in the Gulf of Oman in spring 1977. In addition, 34 neuston tows were made in these areas. Approximately 100 species of phytoplankton were identified. Their numerical abundance ranged from 200 to 42,000 cells per liter. Diatoms were the most diverse taxa while coccolithophores were generally the dominant species numerically. Zooplankton biomass ranged from .11 to 2.00 cc/m^3 and .52 to 2.27 cc/m^3 in the Persian Gulf and Gulf of Oman respectively. Significantly higher volumes were recorded from the Gulf of Oman. The numerical abundance of zooplankton varied from 79 to 5098/m^3. Copepods comprised more than 50% of the zooplankton in over one-half of the collections from the Persian Gulf. Higher zooplankton volumes occurred in the Central Persian Gulf. There was no significant differences in the quantities of zooplankton (** Cont.)

17. Key Words and Document Analysis. 17a. Descriptors

1. Phytoplankton
2. Zooplankton
3. Neuston

17b. Identifiers/Open-Ended Terms

** between day and night. Fourteen species of pontellid copepods were identified in neuston samples from the Persian Gulf and Gulf of Oman, including 10 species that represent new records for the Persian Gulf. Information on tar balls are summarized in an Appendix to this report.

17c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 35
	20. Security Class (This Page UNCLASSIFIED	22. Price

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