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Zooplankton abundance and species diversity in Qui Nhon coastal waters, South Central Vietnam in June 2004

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Abstract—A survey of zooplankton abundance and species diversity was conducted at 17 stations in Thi Nai Lagoon and Qui Nhon Bay in June 2004. A total of 134 species of zooplankton were identified, of which copepods were most diverse with 87 species, comprising 65% of total species of zooplankton, followed by tunicates (7.5%) and chaetognaths (6.7%). Copepods also dominated in abundance, comprising 76% on average of total zooplankton, followed by invertebrate larvae (16%) and tunicates (7.0%). On the basis of the Bray-Curtis similarity index at species levels, the stations were classified into two distinct groups: those in the Lagoon and in the Bay. The abundance of total zooplankton was significantly higher in the Lagoon than in the Bay. In contrast, the species richness d (Margalef's *d*) and the values of diversity index (Shannon-Wiener's *H'*) both were significantly higher in the Bay than in the Lagoon, with the mean values of 9.2 vs 2.6 (*d*) and 3.2 vs 2.3 (*H'*), respectively. In addition, the total number of species was ca. 2.5 times higher in the Bay (122 spp.) than in the Lagoon (48 spp.), among which 86 species occurred only in the Bay while only 12 species were specific to the Lagoon. These indicate that the zooplankton assemblages were highly different between the Lagoon and the Bay, and that in the Lagoon comprises a small number of highly abundant species, while that in the Bay comprises a much larger number of sparsely distributed species. These suggest that this area is an excellent field for studying the functional aspects of biodiversity.

Key words: zooplankton, species richness, abundance, South Central Vietnam

Introduction

Marine plankton in Vietnamese waters have been investigated since the early 20th Century (e.g. Dawydoff 1937, Serene 1937, Hamon 1956, Shirota 1966). These previous studies mainly dealt with species composition, distribution, as well as classification of zooplankton. However, information on recorded species was limited since many previous publications provided only lists of species without illustrations and/or species descriptions, or dealt with taxa wherein our knowledge has been much revised in recent years.

Qui Nhon Bay is located in the southern coast of Central Vietnam and is associated with Thi Nai Lagoon through a narrow path (500–700 m) at the Bay's northern periphery. While the Bay is open to the South China Sea, the Lagoon is highly enclosed and under strong influence of the freshwater run-off from October to February from the Con- and Tan An Rivers (Dang and Nguyen 2003). The Lagoon also receives different kinds of chemical/organic discharges from industrial and agricultural activities of the area, as well as from fish culture in the Lagoon itself (Nguyen and Tong 2004).

Under this circumstance, this study aims at providing with basic information on the distribution and biodiversity of zooplankton in Qui Nhon Bay and Nai Lagoon, including a comprehensive list of zooplankton species, information on abundance at higher taxonomic levels, and species richness with particular reference to potential spatial differences. This study is a part of a project on the study of Bays and Lagoons along the coast of Vietnam for sustainable development and management of marine resources.

Materials and Methods

Zooplankton samples were collected at 17 stations in Thi Nai Lagoon (depth: 1.5–3.0 m) and Qui Nhon Bay (depth: 6.0–41.5 m) on 22–28 June 2004 (Fig. 1). Samples were collected using a conical plankton net (mesh size, 200 μm; mouth diameter, 37 cm; length, 100 cm) towed vertically by hand from near bottom to the surface in the daytime (09:00–15:30 h), and were fixed in 5% buffered formalin/seawater solution.

To determine zooplankton abundance, the samples were fractionated into two size classes: >500 μm and <500 μm with a 500-μm sieve. The organisms retained on the sieve were counted in their entirety, while those passed were again poured on a 25-μm sieve. Those retained on the sieve were washed down on a tray with 50 ml of filtered seawater, stirred well, and a 1-ml sub-sample was taken for counting. The

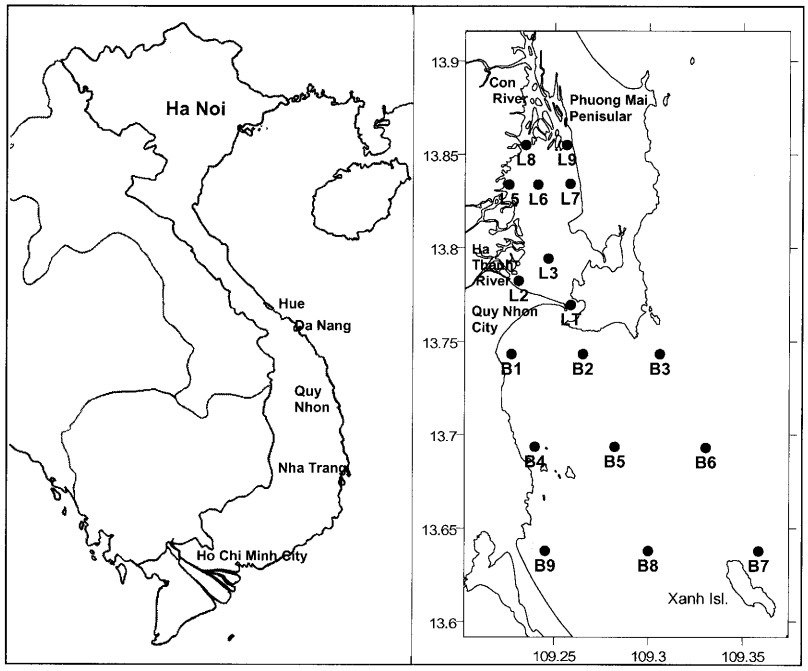

Fig. 1. Map showing the Vietnamese coast line and the sampling stations in Thi Nai Lagoon and Qui Nhon Bay.

abundance of zooplankton at each station was standardized to number per cubic meter on the basis of the distance of tow and the mouth area of the net, assuming a 100% filtration efficiency. Zooplankton species were identified mainly following Chen and Zhang (1965), Chen et al. (1974), Owre and Foyo (1967), Nguyen (1955), Nishida (1985) and Boltovskoy (1999). The abundance of zooplankton was enumerated at the species levels except Cnidaria and Ctenphora, wherein only occurrence/absence was recorded because of the serious damage of the specimens, and invertebrate larvae, wherein only higher taxa were enumerated due to insufficient identification at species levels. Physical condition such as temperature and salinity of water were measured during zooplankton sampling.

As a measure of biodiversity patterns, similarities in the species composition between stations were estimated by the Bray-Curtis index, and the stations were clustered on the basis of the index. The species richness was estimated by the Margalef's index (d), while species diversity was estimated by Shannon–Wiener index (H'). Parametric Z-test were applied to test for the difference in abundance, diversity and species richness between the stations in the Bay and the Lagoon. Calculation of indices and cluster analysis were performed by PRIMER 5 (Primer-E Ldt.) while the statistic tests were done by Exel (Microsoft).

Results

Hydrographic conditions

During the present study, water temperature and salinity in the Lagoon ranged from 25.16 to 26.26°C and from 0.06 to 32.73‰, respectively, with a decrease in salinity from the inner-most to outer stations. The water temperature and salinity in the Bay ranged from 23.82 to 28.00°C and from 31.00 to 34.48‰, respectively, but without marked differences between stations.

Species richness

A total of 134 species of zooplankton were identified, of which copepods showed the largest number of species of 87, comprising 65% of total species number of zooplankton, followed by tunicates (7.5%) and chaetognaths (6.7%) (see Appendix 1). The species richness index d (Margalef) was higher in the Bay (9.2) than in the lagoon (2.6) (Z test, $p<0.05$). In addition, the total number of species was ca. 2.5 times higher in the Bay (122 spp.) than in the Lagoon (48 spp.), among which 84 species occurred only in the Bay while 10 species were specific to the Lagoon (Fig. 2).

Abundance and taxonomic composition

The abundance of total zooplankton (Table 1, Fig. 4A) was significantly different between the Lagoon and the Bay ($p<0.05$), with mean abundance in the Lagoon 12.4 times higher than that in the Bay. Within the Lagoon, the abundance tended to increase from the mouth to the innermost part (northern area) (Fig. 4A). Copepods dominated in abundance, comprising 76% on average of total zooplankton, followed by invertebrate larvae (16%) and tunicates (7.0%) (Table 1).

On the basis of the similarity index (Bray-Curtis, square root transform) at species levels, the stations were classified

into two distinct groups by a dissimilarity level of >70%: those in the Lagoon and in the Bay (Fig. 3). The values of diversity index (H') was significantly higher in the Bay than in the Lagoon ($p<0.05$) with the mean values of 3.2 and 2.3, respectively.

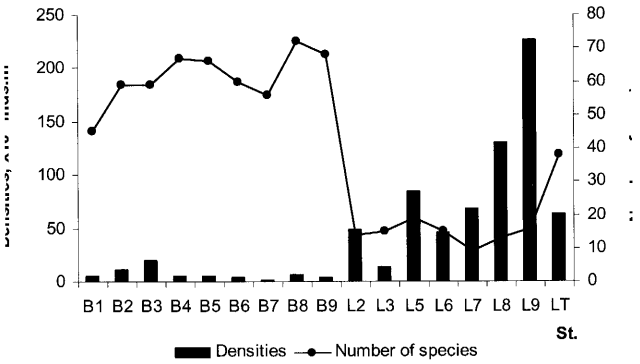

Fig. 2. Variation in zooplankton densities and number of species among stations.

Distributional patterns of higher taxa with notes on species occurrence

There were two distinct patterns in the abundance distribution of higher taxonomic groups (Table 1, Fig. 4B-E). (1) Those occurred at all or most of the stations but were more abundant in the Lagoon than in the Bay: these were Copepoda, Chaetognatha, invertebrate larvae, Tunicata, and Sergestidae. (2) Those occurred only at the stations in the Bay: these were Cladocera (3 spp.), Ostracoda (1 sp.), and

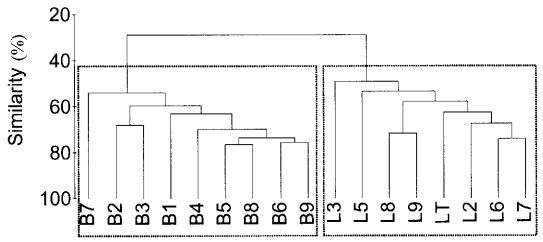

Fig. 3. Cluster analysis of similarity indices showing groups of stations.

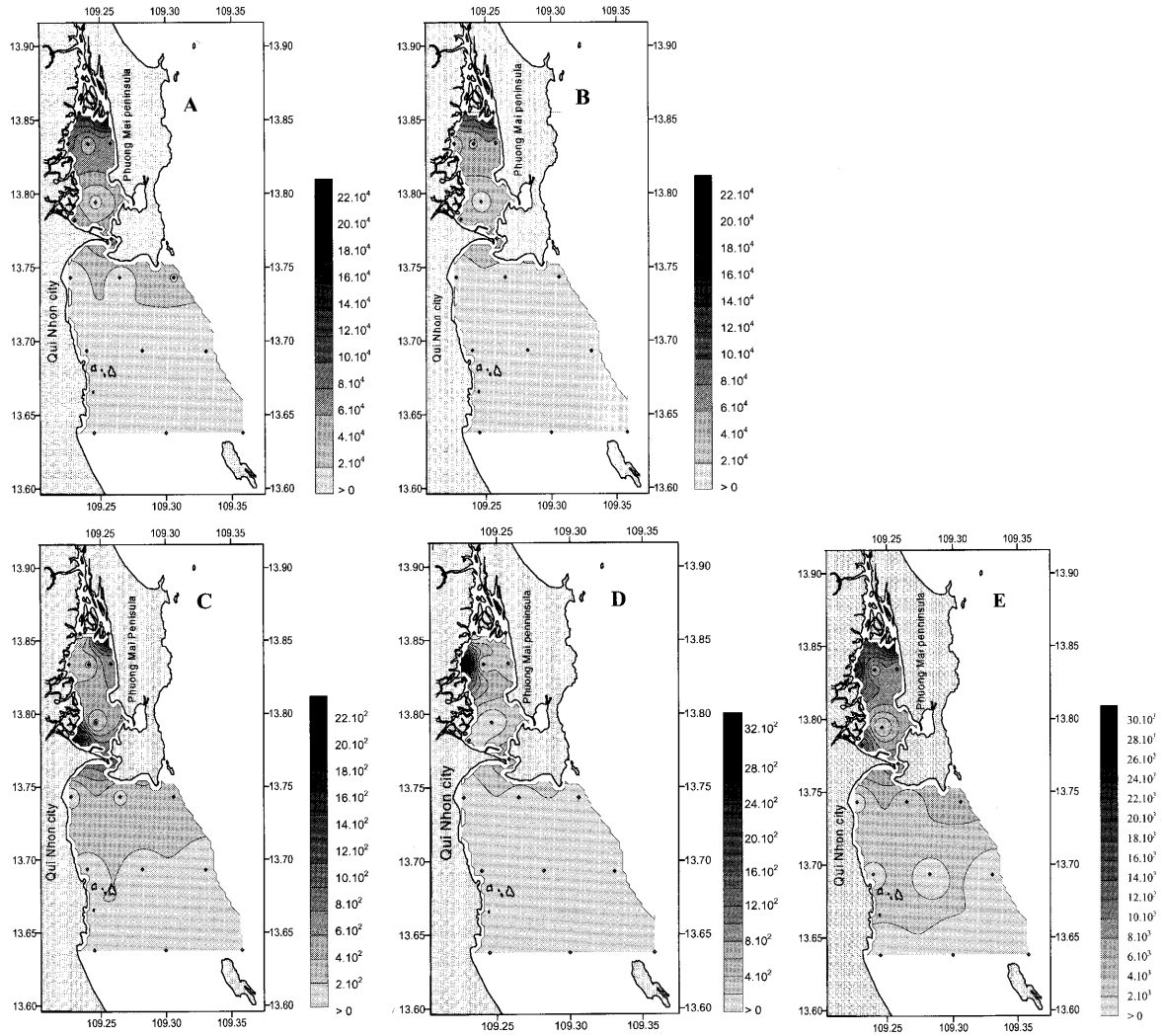

Fig. 4. Distribution of zooplankton abundance (inds.m^{-3}). A, total zooplankton; B, Copepoda; C, Chaetognatha; D, Tunicata; E, invertebrate larvae.

Table 1. Abundance of different zooplankton groups (inds.m^{-3}) in Thi Nai Lagoon and Qui Nhon bay, excluding Cnidaria and Ctenophora.

Taxon	B1	B2	B3	B4	B5	B6	B7	B8	B9	L2	L3	L5	L6	L7	L8	L9	LT	Average	%
Cladocera	4	60	12	54	6	2	0	6	2	0	0	0	0	0	0	0	0	9	0
Ostracoda	2	0	4	52	0	17	0	0	22	0	0	0	0	0	0	0	0	6	0
Copepoda	3566	7349	13716	3118	3415	2228	1511	3379	2738	32780	11443	30540	36590	56780	114170	192880	45828	33061	76
Heteropoda & Pteropoda	0	63	4	12	6	0	4	60	3	0	0	0	0	0	0	0	0	9	0
Sergestidae	4	14	24	6	14	5	7	4	3	180	0	500	490	110	80	320	26	105	0
Isopoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	6	0
Amphipoda	40	0	0	6	0	2	0	0	0	0	0	0	0	0	0	0	0	3	0
Cumacea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40	0	2	0
Chaetognatha	116	151	276	140	127	46	64	98	101	1930	171	200	170	660	130	2480	1088	468	1
Invertebrate larvae	1202	2543	4116	1598	1261	601	51	1170	822	13480	1900	19610	6640	8020	15270	30660	9670	6977	16
Tunicata	326	1200	1644	280	427	372	209	907	392	260	343	33550	1770	3000	250	500	6652	3064	7
Total	5260	11380	19796	5266	5256	3273	1846	5624	4083	48630	13857	84400	45660	68570	129900	226880	63364	43709	100

Heteropoda+Pteropoda (8 spp.).

Among the 87 copepods recorded, 50 species occurred only in the Bay, and included the species commonly recorded in the coastal waters of Southeast Asia, while 8 species were specific to the Lagoon (Appendix 1). The occurrence of the latter species are relatively sporadic, and none of these species occurred at all the stations in the Lagoon, e.g. 2 out of 8 stations in *Acartia* sp., *Longipedia weberi*, and *Pseudodiaptomus annandalei*, and only one station in *Harpacticus* sp. Among the 9 species of chaetognaths, 7 occurred only in the Bay. *Sagitta delicata* was specific to the Lagoon, while *S. enflata* occurred in the both. Of the 2 sergestid decapods, *Lucifer hanseni* occurred only in the Lagoon, while *L. penicillifer* was specific to the Bay. Among the 10 tunicates, 7 occurred only in the Bay, while *Fritillaria formica*, *Oikopleura fusiformis* and *O. longicauda* occurred in both areas. The invertebrate larvae comprised gastropods, bivalves, polychaetes, decapods, echinoderms, tornarians, and cirripeds.

Discussion

The present study recorded the occurrence of 134 zooplankton species, including 87 copepods, from Nai Lagoon and Qui Nhon Bay in Central Vietnam. This appears to be a large number, compared with previously recorded numbers of zooplankton (212 species) and copepod species (127 species) from Vietnamese waters (Nguyen et al. 1991), given that the present collection is based on one-time survey in a relatively small area. This species diversity was contributed largely by the species occurring in the Bay, presumably representing the coastal-water fauna in the South China Sea. All the present species had been recorded from the Vietnamese waters.

The much higher abundance of zooplankton in the Lagoon than in the Bay, particularly in the inner-most part, is consistent with the eutrophicated condition of the Lagoon, as exemplified by the high levels of Chl-a 105.71+71.02 mg·m^{-2} (Nguyen and Tong 2004). This discrepancy in abundance pattern was in sharp contrast to the patterns in diversity, as indicated by both the species richness and the diversity index (H'), the values of which were significantly higher in the Bay than in the Lagoon. The species numbers at the Bay stations may be highly conservative estimates, since these are based on much smaller numbers of specimens than in the Lagoon stations.

On the basis of the present results, it is suggested that the zooplankton assemblage in the Lagoon consisted of a small number of highly abundant species, while that in the Bay comprised a much larger number of sparsely distributed species. It was also indicated that there were three major occurrence patterns, both at the species and higher-taxon levels: the Lagoon-specific, the Bay-specific, and the non-spe-

cific taxa. The Lagoon-specific taxa are assumed to tolerate and can reproduce in the highly variable, low saline, and eutrophicated environment of the Lagoon, but cannot reproduce in the Bay waters, while the Bay-specific taxa may be poorly adapted to survive in the Lagoon. The non-specific taxa may have their center of distribution in either areas, but can survive, or even reproduce, in the other area.

The discrepancy of zooplankton assemblages between lagoons and surrounding coastal waters, as seen in the present study, has also been reported from other regions of the Indo-Pacific, such as on copepods in Cochin Backwater, India (Chandrasekhan 1971, Ravindranatha et al. 1971) and in Ishigaki Island, Japan (Nishida 1985). However, to our knowledge, this is the first report of this phenomenon in the Vietnamese waters, and suggests that the present area would be an excellent field for studying the functional aspects of biodiversity, necessitating further studies on the temporal changes of the zooplankton assemblages, species' life histories, and trophic dynamics in the Lagoon and the Bay.

Acknowledgements

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Appendix 1. Species list of zooplankton in Thi Nai Lagoon and Qui Nhon Bay in June 2004.

TT	Taxon	Stations																
		B1	B2	B3	B4	B5	B6	B7	B8	B9	L2	L3	L5	L6	L7	L8	L9	LT
	Hydromedusae																	
1	*Aglaura hemistoma*		+	+	+	+	+	+	+	+	+					+		
2	*Obelia* sp.										+	+	+	+	+		+	+
3	*Sarsia* sp.	+	+	+	+	+	+	+	+	+		+	+	+		+	+	
4	*Solmundella bitentaculata*								+									
	Siphonophora																	
1	*Abyla* sp.			+														
2	*Abylopsis eschscholtzi*				+				+									
3	*Agalma* sp.									+								
4	*Chelophyes appendiculata*	+				+		+										
5	*Diphyes chamissonis*			+	+	+	+	+	+	+								
6	*Eudoxoides spiralis*			+	+	+			+	+								
7	*Lensia subtiloides*	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
8	*sulculeolaria* sp.								+									
	Ctenophora																	
1	*Pleurobrachia pileus*				+						+			+	+	+	+	
	Cladocera																	
1	*Penilia avirostris*	+	+	+	+	+	+		+									
2	*Pleopis schmackeri*				+													
3	*Pseudevadne tergestina*					+	+		+	+								
	Ostracoda																	
1	*Conchoecia* sp.	+		+	+		+			+								
	Copepoda																	
1	*Acartia danae*			+				+		+								
2	*Acartia erythraea*	+	+	+													+	+
3	*Acartia negligens*		+	+	+	+	+	+	+	+								
4	*Acartia pacifica*		+															
5	*Acartia* sp.												+				+	
6	*Acrocalanus gibber*	+	+	+	+	+	+		+	+								+
7	*Acrocalanus gracilis*		+	+	+	+	+	+	+	+								
8	*Acrocalanus monachus*					+		+		+								
9	*Calanopia minor*		+															
10	*Calanus sinicus*									+								
11	*Calocalanus pavo*	+	+	+	+	+	+	+	+	+								
12	*Calocalanus plumulosus*		+	+	+	+	+	+	+	+								+
13	*Calocalanus styliremis*	+	+	+	+	+	+	+	+	+								
14	*Candacia catula*		+	+	+		+		+									
15	*Candacia truncata*			+		+		+		+								
16	*Canthocalanus pauper*	+	+	+	+	+	+	+	+	+								+
17	*Centropages calaninus*									+								
18	*Centropages dorsispinatus*																	+
19	*Centropages furcatus*							+										
20	*Centropages gracilis*		+															
21	*Centropages orsinii*	+		+														
22	*Clausocalanus arcuicornis*	+	+	+	+	+	+	+	+	+								
23	*Clausocalanus furcatus*	+	+	+	+	+	+	+	+	+								+
24	*Clausocalanus pergens*							+	+									
25	*Copilia mirabilis*		+	+	+	+	+	+	+	+								
26	*Copilia quadrata*					+			+									
27	*Corycaeus agilis*		+		+		+	+		+								
28	*Corycaeus andrewsi*	+	+	+		+			+									+
29	*Corycaeus asiaticus*	+	+		+	+	+	+		+								
30	*Corycaeus catus*			+					+	+								
31	*Corycaeus concinnus*						+	+		+								
32	*Corycaeus crassiusculus*									+								
33	*Corycaeus dahli*	+	+	+	+		+	+	+	+								

Appendix 1. Continued.

		B1	B2	B3	B4	B5	B6	B7	B8	B9	L2	L3	L5	L6	L7	L8	L9	LT
34	*Corycaeus erythraeus*	+	+		+		+			+								
35	*Corycaeus gibbulus*	+		+	+	+	+	+	+	+								+
36	*Corycaeus lautus*								+									
37	*Corycaeus longistylis*			+		+	+		+									+
38	*Corycaeus lubbocki*	+	+	+	+	+	+		+	+			+					+
39	*Corycaeus* sp.	+	+	+	+	+	+	+	+	+		+	+					+
40	*Corycaeus speciosus*		+	+	+	+		+		+								
41	*Eucalanus pseudattenuatus*				+			+		+								
42	*Eucalanus subcrassus*	+	+	+	+	+	+	+	+	+								+
43	*Eucalanus subtenuis*					+												
44	*Euchaeta concinna*					+				+								
45	*Euterpina acutifrons*	+	+	+	+	+	+		+		+	+	+	+	+			+
46	*Labidocera minuta*		+		+				+	+								
47	*Longipedia weberi*													+		+		
48	*Lucicutia flavicornis*				+	+												
49	*Lucicutia ovalis*				+	+				+								
50	*Mecynocera clausi*	+	+	+	+	+	+	+	+	+								+
51	*Microsetella norvegica*	+	+	+	+	+	+	+	+	+			+					+
52	*Nanocalanus minor*					+			+									
53	*Neocalanus gracilis*								+									
54	*Oithona attenuata*	+		+							+	+						+
55	*Oithona brevicornis*																	+
56	*Oithona fallax*		+	+	+	+	+	+	+	+			+					+
57	*Oithona nana*	+	+	+		+	+	+			+	+	+	+	+	+	+	+
58	*Oithona plumifera*	+	+	+	+	+	+	+	+	+								+
59	*Oithona rigida*		+	+								+	+					+
60	*Oithona similis*	+																
61	*Oithona simplex*	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
62	*Oithona tenuis*	+	+	+	+	+	+	+	+	+								+
63	*Oncaea conifera*	+	+	+	+	+	+	+	+	+								+
64	*Oncaea mediterranea*		+	+	+	+	+	+	+	+								
65	*Oncaea similis*	+	+					+		+								
66	*Oncaea* sp.	+	+	+	+	+	+	+	+	+	+	+					+	+
67	*Oncaea venusta*				+	+	+	+	+	+								
68	*Paracalanus aculeatus*	+	+		+	+	+		+	+								
69	*Paracalanus crassirostris*	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
70	*Paracalanus gracilis*	+	+	+	+	+	+	+	+	+			+					+
71	*Paracalanus parvus*	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
72	*Calocalanus pavo*												+					
73	*Pontellina plumata*								+									
74	*Pseudodiaptomus incisus*				+						+		+					+
75	*Pseudodiaptomus annandalei*															+	+	
76	*Sapphirina nigromaculata*			+														
77	*Scolecithrix danae*				+		+		+	+								
78	*Scolecithrix nicobarica*	+	+	+			+		+									
79	*Setella gracilis*				+	+	+	+		+								
80	*Temora discaudata*			+		+		+	+	+								+
81	*Temora stylifera*	+	+	+	+	+	+	+	+	+								+
82	*Temora turbidata*		+															
83	*Tortanus forcipatus*																	+
84	*Undinula darwinii*					+	+			+								
85	*Undinula vulgaris*				+				+									
86	*Phaenna spinifera*					+												
87	*Harpacticus* sp.													+				
	Heteropoda & Pteropoda																	
1	*Agdina* sp.								+									
2	*Atlanta fusca*		+	+														
3	*Creseis acicula*		+						+									
4	*Creseis clava*									+								

Appendix 1. Continued.

		B1	B2	B3	B4	B5	B6	B7	B8	B9	L2	L3	L5	L6	L7	L8	L9	LT
5	*Creseis virgula*								+									
6	*Desmopterus papilio*				+	+		+	+									
7	*Limacina bulimoides*				+													
8	*Limacina trochiformis*		+		+	+												
	Sergestidae																	
1	*Lucifer hanseni*										+			+		+	+	
2	*Lucifere penicillifer*				+				+									
	Cumacea																	
1	*Bodotria* sp.																+	
	Chaetognatha																	
1	*Krohnitta pacifica*	+			+		+	+										
2	*Pterosagitta draco*				+	+		+	+	+								
3	*Sagitta delicata*											+		+			+	+
4	*Sagitta enflata*	+	+	+	+	+	+	+	+	+						+		+
5	*Sagitta hexaptera*					+												
6	*Sagitta neglecta*				+	+		+										
7	*Sagitta pacifica*				+													
8	*Sagitta regularis*								+									
9	*Sagitta robusta*	+								+								
	Tunicata																	
1	*Dolioletta gegenbauri*			+	+	+	+	+	+	+								
2	*Fritillaria formica*		+				+	+	+	+								+
3	*Fritillaria haplostoma*						+											
4	*Fritillaria pellucida*	+	+	+	+	+	+	+	+	+								
5	*Fritillaria* sp.		+	+	+	+	+		+									
6	*Fritillaria venusta*					+	+											
7	*Megalocercus huxleyi*								+									
8	*Oikopleura fusiformis*	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
9	*Oikopleura longicauda*	+	+	+	+	+	+	+	+	+		+	+	+				
10	*Oikopleura rufescens*								+									
	#Species	45	59	59	67	66	60	56	72	68	14	15	19	15	9	13	16	38