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Seasonal Relationships between the Plankton Community and Hydrographic Conditions in a Shallow Oligotrophic Bay, Gulf of Thailand

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ABSTRACT

The variability in a plankton community was studied twice a week from September 2006 to August 2007 in a shallow bay (Manao Bay, Gulf of Thailand). Phytoplankton was collected by filtering with a 20 μm plankton net and zooplankton was collected by vertical hauling with a plankton net of 200 μm mesh size. Hydrographic conditions were measured *in situ*, while water samples were analyzed for nutrient content in the laboratory. Fifty-six genera of phytoplankton and 37 groups of zooplankton were recorded. The mean abundance of phytoplankton was 4,930 ± 2,801 unit l^{-1} while that of zooplankton was 3,380 ± 1,264 individuals m^{-3} (ind. m^{-3}). The dominant groups of phytoplankton were centric diatoms and pennate diatoms, while copepods and meroplankton were the major contributors of zooplankton. The plankton community did not differ in species composition and abundance between the two monsoon seasons and there were no specific noticeable characteristics. Hydrographic conditions showed slight fluctuations and nutrients had low values. Additionally, low average primary production (1.30 ± 0.67 mg m^{-3}) was influenced by water temperature, rainfall, salinity, silicate content and dissolved inorganic nitrogen. This bay was characterized as a tropical oligotrophic coastal water.

Key words: plankton community, abundance, hydrographical conditions, nutrients, the Gulf of Thailand

INTRODUCTION

The plankton community is an important trophic structure in the marine ecosystem. In the sea, a flow of energy and organic matter can be observed between phytoplankton (primary producers) and zooplankton (consumers) (Runge, 1988; Calbet and Landry, 2004; Calbet, 2008). Additionally, plankton is a sensitive indicator of environmental disturbance (Laane *et al.*, 1996; Howarth and Marino, 2006; McQuatters-Gallop *et al.*, 2007). The relationship between the hydrographic characteristics and community structure could shape variability in the biodiversity, abundance and distribution of planktonic populations and also might indicate the potential of a marine ecosystem (Turner *et al.*, 1998; Philippart *et al.*, 2000; Munk *et al.*, 2003). Environmental factors affect phytoplankton growth in terms of essential nutrients which increase phytoplankton production and are related to zooplankton production and fish stocks across the trophic structure or food web (Landry *et al.*, 1995; Reid *et al.*, 2000; Turner, 2004).

Detailed information on the plankton food web structure is not available in the Gulf of

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Thailand. Many studies have focused on phytoplankton diversity (Boonyapiwat, 1999; Tieanpisut, 2006; Patarajinda *et al*., 2007; Rattanapun, 2007) or zooplankton diversity (Sribyatta, 1996; Jivaluk, 1999; Srinui, 2007). However, few studies looked at these two components at the same location (Pienpichit, 1999; Panchote, 2005). Relationships between the plankton community and environmental factors were established by Thongbor (2004), Boondao (2006) and Permsirivanich (2007). Unfortunately, they have not been recorded for the upper western coastal area of the Gulf of Thailand. Manao Bay is a small, semi-enclosed bay with a shallow water body influenced by two different monsoon seasons giving a characteristic combination of wet and dry periods in an annual cycle. It represents a good area to study plankton communities. Therefore, the aim of this study was to investigate the major environmental factors influencing the seasonal variability of the plankton community in Manao Bay.

MATERIALS AND METHODS

Manao Bay (11° 49′N, 99° 50′E) is a shallow, protected bay located on the upper western coast of the Gulf of Thailand (Figure 1). As this area has been under the control of the Royal Thai Air Force, it is relatively undisturbed by fisheries, freshwater runoff and transportation (Jansang *et al*., 1999). It is classified as a small, semi-enclosed bay of approximately 15 km^2 surface area with a mean depth of 7 m. Circulation of coastal water is affected by tidal currents and the tide is variable. The surface current (0-10m) is strongly influenced by prevailing monsoons and this area is affected by two heavy monsoons; the southwest monsoon from May to October and the northeast monsoon from November to February. The surface vector field is northeastward in the Gulf from the South China Sea during the northeast monsoon and the opposite direction in the southwest monsoon (Robinson, 1963; Snidvongs and Sojisuporn, 1999).

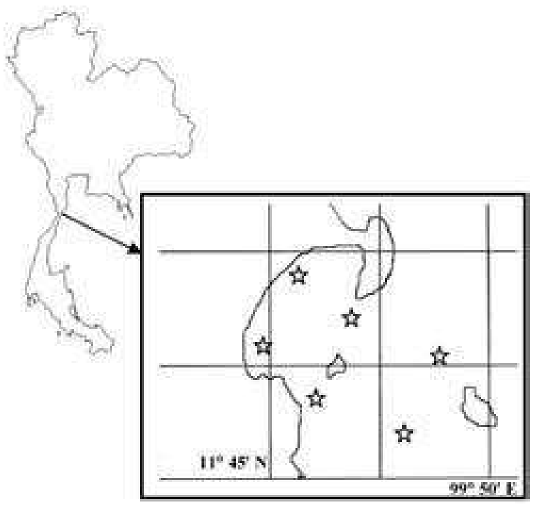

Figure 1 Geographic location of Manao Bay (11° 49′N, 99° 50′E), showing position of sampling stations in the inner, middle and outer area of the bay.

Plankton sampling and recording of the hydrographic conditions were carried out during daylight twice a week from September 2006 to August 2007. Six sampling stations along two transect lines were established in three areas: an inner station (average depth of 3 m), middle station (average depth of 7 m) and outer station (average depth of 10 m) (Figure 1). At each station, hydrographic conditions were measured *in situ* for water temperature and dissolved oxygen (using a DO meter, YSI 550), salinity (refractometer, Asahi) and pH (pH meter, YSI 60). Monthly mean precipitable water data were obtained from the Thai Meteorological Department (http://www.tmd.go.th/province_stat). Water samples were collected from a depth of 50 cm below the surface. Water samples were analyzed in the laboratory for their nutrient content (nitrite, nitrate, ammonia, orthophosphate, silicate) (APHA, AWWA and WEF, 1998). Chlorophyll a concentration was determined by a spectrophotometric method (Strickland and Parsons, 1972).

Phytoplankton was collected by a filtering technique. Twenty liters of sub-surface seawater was filtered through a plankton net of 20 μm mesh size. Zooplankton was collected by vertical hauling with a conical 0.6 m diameter plankton net of 200 μm mesh size, with two replications per station. The net was fitted with a flow meter to determine the amount of water filtered during each tow. Net samples were immediately preserved in 5% buffered formaldehyde solution.

Genera identification and enumeration of phytoplankton samples were carried out in the laboratory using a microscope. Phytoplankton was counted in terms of the number of cells, filaments or colonies. The abundance of phytoplankton was expressed as the number of units per liter. Zooplankton samples were identified to higher groupings and abundance was expressed as the number of individuals m^{-3} (ind. m^{-3})(Postel *et al.*, 2000). Pearson correlation analysis was used to determine relationships between the hydrographical variables and the total abundance of phytoplankton and zooplankton (Legendre and Legendre, 1983).

RESULTS

Hydrographical variables and nutrients

Figure 2 shows the annual cycle in the hydrographic data and nutrient values in Manao Bay. The water temperature ranged between 26.0°C in January 2007 to 31.4°C in June 2007. Salinity values varied from 21 psu in June 2007 to 31 psu in November 2006. Water temperature and salinity showed distinct seasonal variations. The pH fluctuated between 7.71 and 8.19. Dissolved oxygen varied between a minimum of 4.87 mg l^{-1} in September 2006 and a maximum of 10.69 mg l^{-1} in August 2007. The average monthly precipitation over 30 years showed a clear trend with a maximum of 226.7 mm in November and a minimum of 41mm in April. This trend related to the two monsoon seasons; hence, the increase during the southwest monsoon is the wet season (May-October) and the decrease during the northeast monsoon is the dry season (November-February). The summer months of March and April also had rainfall at a minimum level.

Chlorophyll a concentration ranged between 0.24 mg m^{-3} in December 2006 and 2.67 mg m^{-3} in June 2007, with an average value of 1.30 ± 0.67 mg m^{-3} over the sampling period. Chlorophyll a values regularly changed with two peaks in concentration: a small one (2.14 mg m^{-3}) in October 2006 and a large one (2.67 mg m^{-3}) in June 2007 during the southwest monsoon. The lowest concentration of total chlorophyll a was recorded during the northeast monsoon season.

Nitrite values fluctuated with a minimum of 0.002 mg l^{-1} in February 2007 and a maximum of 0.009 mg l^{-1} in August 2007. Nitrate values ranged between 0.004 mg l^{-1} in November 2006 and 0.018 mg l^{-1} in March 2007. Ammonia varied from 0.027 mg l^{-1} in February and May 2007 to 0.088 mg l^{-1} in November 2006. Dissolved inorganic nitrogen (nitrite, nitrate and ammonia) fluctuated between 0.035 mg l^{-1} in February 2007 and 0.097 mg l^{-1} in November 2006. Silicate values varied from 0.393 mg l^{-1} in January 2007 to 1.278 mg l^{-1} in December 2006. Orthophosphate fluctuated between 0.004 mg l^{-1} in February 2007 and 0.013 mg l^{-1} in November 2006 (Figure 2). During the annual cycle, nutrient values showed distinct seasonal patterns and fluctuated in narrow ranges.

Plankton community

Phytoplankton

A total of 56 genera of phytoplankton were recorded. They consisted of four classes: Cyanophyceae (blue-green algae), Bacillariophyceae (centric and pennate diatoms), Dinophyceae (dinoflagellates) and Dictyochophyceae (silicoflagellates). The centric diatom samples were the most diverse group,

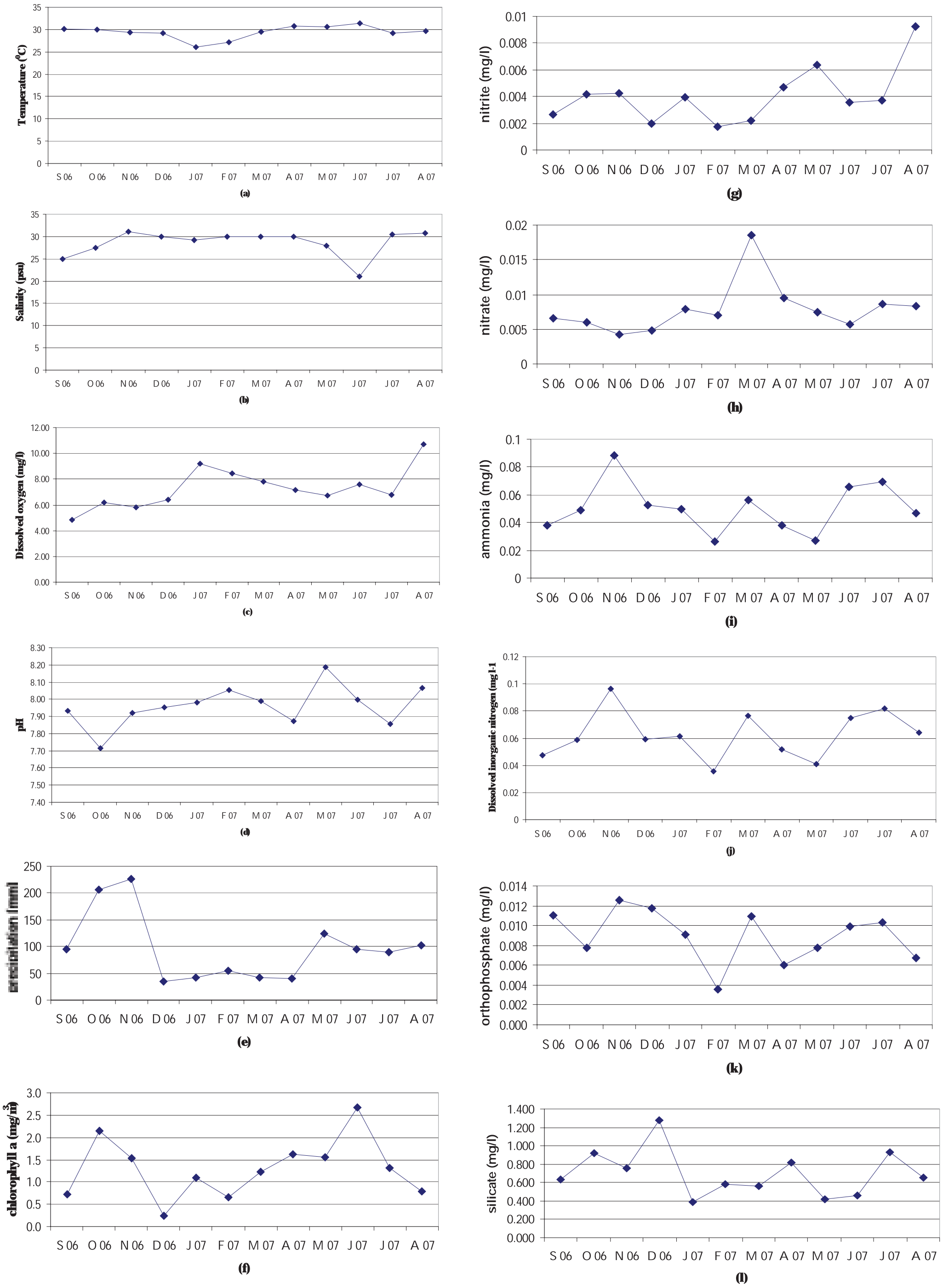

Figure 2 The annual cycle in average hydrographical conditions in Manao Bay; (a) water temperature; (b) salinity; (c) dissolved oxygen ; (d) pH; (e) precipitation;(f) chlorophyll a concentration; (g) nitrite; (h) nitrate; (i) ammonia; (j) dissolved inorganic nitrogen; (k) orthophosphate; and (l) silicate.

comprising 26 genera, followed by pennate diatoms (18 genera), dinoflagellates (8 genera), blue-green algae (3 genera) and silicoflagellates (1 genus), respectively (Table 1). The number of genera ranged from 28 in February to 41 in April, May and August 2007.

The total abundance of phytoplankton varied during the period of study from a minimum of 1,379 unit l^{-1} in September 2006 to a maximum of 10,506 unit l^{-1} in January 2007 (Figure 3). The mean abundance was 4,930 ± 2,801 unit l^{-1}. The variation in abundance of phytoplankton regularly changed, having three peaks, with the highest one (10,506 unit l^{-1}) in January 2007 and two smaller ones (8,308 and 8,829 unit l^{-1}) in May and August, respectively. The peak of maximum abundance coincided with the abundance of *Nitzschia*, *Bacteriastrum*, *Rhizosolenia* and *Chaetoceros*, while the graph shows fairly constant abundance values between February to April.

No noticeable variation in seasonal abundance of phytoplankton during the two monsoon seasons was apparent in the study area. During the southwest monsoon (May-October), the average abundance of phytoplankton was 5,158 ± 3,033 unit l^{-1} while an average value of 5,290± 3,734 unit l^{-1} was recorded during the northeast monsoon (November-February) (Figure 4a). The lowest average abundance was 3,530 ± 8 unit l^{-1} in summer (March-April).

The contribution of the various phytoplankton groups was dominated by centric diatoms, comprising 49.86% of the total abundance. The mean value was 2,458 ± 1,842 unit l^{-1}. Pennate diatoms comprised 36.18% (1,784 ± 1,362 unit l^{-1}), followed by blue-green algae

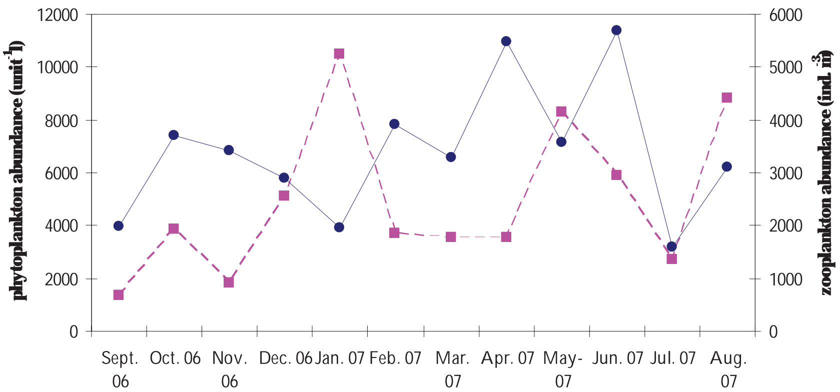

Figure 3 Total abundance of phytoplankton (– – –) and zooplankton (——) in Manao Bay.

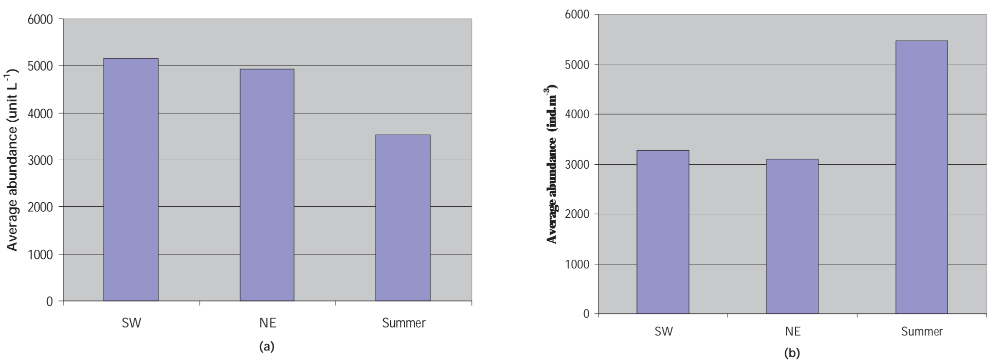

Figure 4 Seasonal average abundance of (a) phytoplankton and (b) zooplankton in Manao Bay.

Table 1 Phytoplankton diversity with mean, maximum and minimum values of abundance (unit l^{-1}), and mean value for contribution (%) to total abundance of each taxon.

Taxa	Abundance (unit l^{-1})			Mean %
	Mean	Max	Min	
DIVISION CYANOPHYTA				
CLASS CYANOPHYCEAE				
Oscillatoria	367	666	0	7.44
Cylindrospermopsis	94	849	0	1.90
Richelia	59	388	0	1.19
DIVISION CHROMOPHYTA				
CLASS BACILLARIOPHYCEAE				
ORDER BIDDULPHIALES				
Cyclotella	0.14	1.73	0	0
Lauderia	41	165	2.5	0.82
Skeletonema	1.22	12	0	0.02
Thalassiosira	0.57	3.75	0	0.01
Planktoniella	3	27	0	0.06
Stephanodiscus	0.66	5	0	0.01
Paralia	7	15	0	0.15
Melosira	23	154	0	0.47
Corethron	8	77	0	0.16
Palmeria	0.40	3	0	0.01
Coscinodiscus	307	2223	23	6.23
Pseudoguinardia	32	116	0	0.66
Actinoptychus	1.4	11	0	0.03
Asteromphalus	4	13	0	0.08
Dactyliosolen	3	24	0	0.06
Guinardia	89	564	4.12	1.80
Proboscia	383	1948	6	7.76
Pseudosolenia	111	900	0	2.24
Rhizosolenia	443	1543	0	8.99
Eucampia	13	43	0.43	0.27
Hemiaulus	87	371	9	1.77
Bacteriastrum	380	1961	4	7.72
Chaetoceros	385	1178	0.48	7.81
Ditylum	79	660	0	1.60
Odontella	41	144	6	0.82
Triceratium	16	185	0	0.32
ORDER BACILLARIALES				
Asterionella	7	61	0	0.13
Synedra	52	626	0	1.06
Thalassionema	450	1294	44	9.12
Thalassiothrix	0.65	4	0	0.01
Amphora	0.32	3	0	0.01

Gyrosigma	17	36	0.41	0.35
Navicula	8	26	0	0.16
Pleurosigma	647	1948	25	13.12
Climacosphenia	0.14	1.28	0	0
Meunier	46	223	0	0.93
Nitzschia	419	733	0	8.50
Bacillaria	39	154	8	0.79
Pseudo-nitzschia	87	444	8	1.76
Cylindrotheca	0.70	7	0	0.01
Cocconeis	0.12	1.4	0	0
Epithemia	0.03	0.33	0	0
Surirella	7	32	0	0.14
Entomoneis	5	20	0	0.10
CLASS DINOPHYCEAE				
Prorocentrum	2	7	0	0.03
Dinophysis	32	169	0	0.66
Ornithocercus	0.60	5	0	0.01
Noctiluca	2	8	0	0.03
Ceratium	81	190	20	1.64
Pyrophacus	11	33	0	0.22
Peridinium	6	17	0	0.11
Protoperidinium	28	58	1	0.57
CLASS DICTYOCHOPHYCEAE				
Dictyocha	8	31	0	0.16

(10.53%, 519 ± 365 unit l^{-1}), dinoflagellates (3.27%, 161 ± 117 unit l^{-1}) and silicoflagellates (0.16%, 7.8 ± 9.2 unit l^{-1}), respectively (Table 1). Eight important genera that frequently occurred in terms of relative abundance were: *Pleurosigma* (13.12%), *Thalassionema* (9.12%), *Rhizosolenia* (8.99%), *Nitzschia* (8.5%), *Chaetoceros* (7.81%), *Proboscia* (7.76%), *Bacteriastrum* (7.72%) and *Oscillatoria* (7.44%).

Diatoms dominated with a high percentage composition for most of the year during the southwest and northeast monsoons (Figure 5).

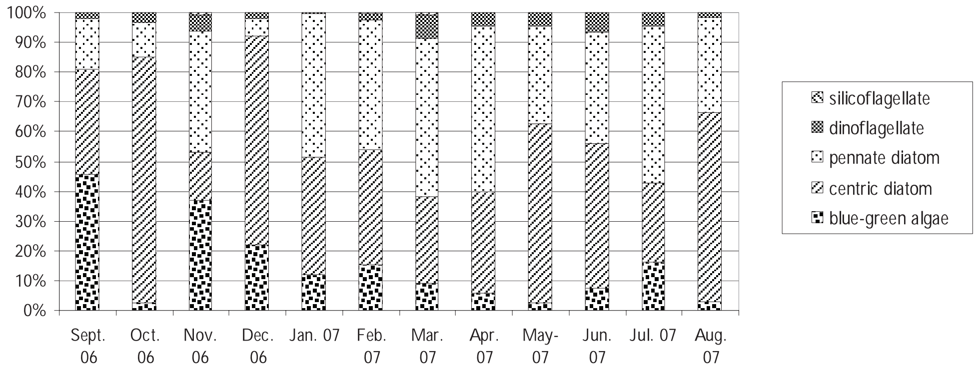

Figure 5 Temporal contribution percentage of phytoplankton in Manao Bay.

A shift in dominant group developed from centric diatoms to pennate diatoms during the period from November 2006 to April 2007. Blue-green algae numbers were high in September 2006 but dinoflagellates and silicoflagellates had low composition percentages throughout the study period.

Zooplankton

Zooplankton belonging to nine phyla were recorded: Sarcomastigophora, Cnidaria, Annelida, Mollusca, Arthropoda, Chaetognatha, Echinodermata, Urochordata and Chordata. They were identified into 37 groups (Table 2). Crustaceans made up the majority of groups, being mainly copepods and decapod larvae. Another common group was the meroplankton, which was composed of: polychaete larvae, mollusc larvae, cirripede nauplii, echinoderm larvae and fish larvae. The number of groups ranged from 19 in December 2006 to 31 in October 2006.

Total abundance of zooplankton varied from a minimum of 1,582 ind. m^{-3} in July 2007 to a maximum of 5,676 ind. m^{-3} in June 2007. The mean abundance was 3,380 ± 1,264 ind. m^{-3} (Figure 3). Two peaks in abundance were reached in April and June 2007, which coincided with the abundance of bivalve veligers, copepodid larvae, protozoea of *Lucifer*, protozoea of *Acetes*, calaonoid copepods and *Sagitta* spp.. Three minimum values were found in September 2006, January 2007 and July 2007. The average abundance of zooplankton was highest (4,380 ± 1536 ind. m^{-3}) in the summer period (March-April), followed by the southwest monsoon season (3,269 ± 1,456 ind. m^{-3}) and the northeast monsoon season (3,045 ± 834 ind. m^{-3}), respectively (Figure 4b).

The larval stages (copepodid) of copepods dominated other groups, contributing 35% to total zooplankton abundance. The mean value was 1,173 ± 443 ind. m^{-3} (Table 2). The four subdominant groups were calanoid copepods (11%), bivalve veligers (8%), *Sagitta* spp. (7%) and protozoea of *Lucifer* (6%). Other groups had generally low abundance with < 5% or absent in some months.

Figure 6 shows the proportion in percentages of the main zooplankton groups in the sampling period. The most important group was the copepods, which generally dominated, having the highest percentage compared to the other groups. While mollusc larvae and other crustaceans increased their percentages in summer (March-April) and the southwest monsoon (May to August 2007) an exception was recorded in July 2007 where copepods comprised > 60% of total zooplankton abundance.

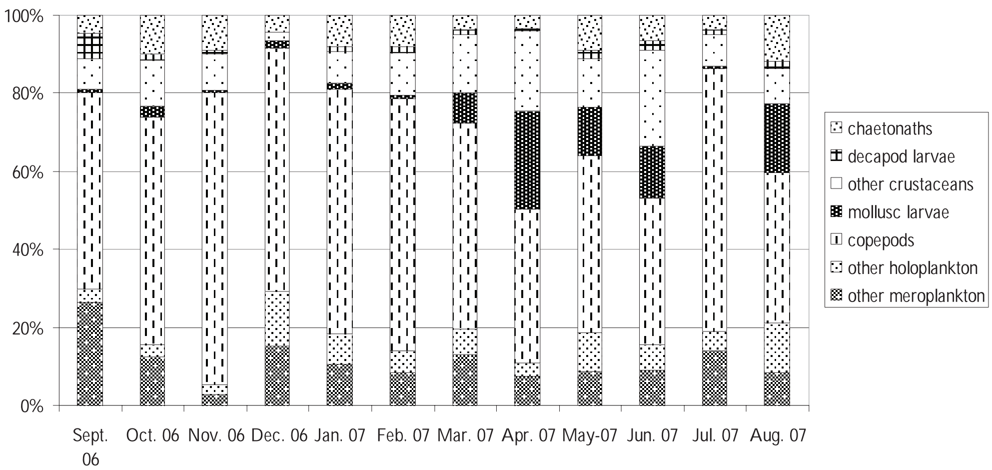

Figure 6 Temporal contribution percentage of zooplankton in Manao Bay.

Table 2 Zooplankton diversity with mean, maximum and minimum values of abundance (inds.m^{-3}), mean value for contribution (%) to total abundance of each taxon.

Taxa	Abundance (inds.m^{-3})			Mean %
	Mean	Max	Min	
Foraminifera	0.7	6	0	0.02
Radiolaria	18	54	0	0.52
Hydromedusae	45	96	10	1.32
Polychaete larvae	77	223	8	2.28
Gastropod veliger	39	120	0	1.16
Bivalve veliger	266	1268	7	7.86
Pteropoda	33	81	0	0.98
Penilia avirostris Dana	7	20	0	0.22
Pseudevadne tergestina Claus	37	182	0	1.08
Ostracoda	6	15	0	0.18
Copepod nauplii	17	73	0	0.52
Copepodid larvae	1173	1966	440	34.72
Calanoida	360	725	104	10.62
Poecilostomatoida	183	284	55	5.42
Harpacticoida	33	197	0	0.99
Cirrepede nauplii	153	478	16	4.53
Cypris larvae	28	211	0	0.82
Alima larvae	0.7	4	0	0.02
Mysidacea	3	23	0	0.09
Amphipoda	0.6	4	0	0.02
Protozoea of *Lucifer*	218	740	25	6.45
Lucifer sp.	90	447	4	2.67
Protozoea of *Acetes*	12	59	0	0.37
Acetes sp.	75	499	0	2.23
Shrimp larvae	24	113	0	0.72
Brachyuran zoea	31	136	5	0.92
Brachyuran megalopa	0.9	6	0	0.03
Porcellanid larvae	0.3	3	0	0.01
Sagitta spp.	233	371	58	6.88
Bipinnaria larvae	0.9	4	0	0.03
Echinopluteus larvae	7	18	0	0.20
Ophiopluteus larvae	79	313	0	2.34
Oikopleura sp.	122	322	24	3.61
Doliolum sp.	0.2	2	0	0.01
Salpa sp.	2	19	0	0.05
Fish eggs	1	7	0	0.04
Fish larvae	3	10	0	0.08

Hydrographic condition, nutrients and plankton abundance

Table 3 shows the Pearson correlation analysis between hydrographic conditions, nutrients and plankton abundance. The analysis indicated that chlorophyll a concentration was positively correlated to temperature (r=0.511, P<0.05), rainfall (r=0.451, P<0.05), ammonia (r=0.305, P<0.05) and dissolved inorganic nitrogen (r=0.312, P<0.05), while it showed a negative correlation with salinity (r=-0.0557, P<0.05) (Table 3). Other hydrographic conditions (dissolved oxygen, pH) and nutrients (nitrite, orthophosphate, silicate) were not correlated to chlorophyll a concentration.

Phytoplankton abundance was positively correlated to nitrite (r=0.537, P<0.5), dissolved oxygen (r=0.708, P<0.5) and pH (r=0.529, P<0.5), while it was negatively correlated to silicate (r=-0.431, P<0.5). However, phytoplankton abundance showed no correlation with nitrate, ammonia, orthophosphate, chlorophyll a concentration, salinity or water temperature.

Zooplankton abundance was positively related to chlorophyll a concentration (r=0.62, P<0.05), dissolved oxygen (r=0.303, P<0.05) and nitrate (r=0.426, P<0.05). Hence, when the chlorophyll a concentration was high, the zooplankton abundance seemed to increase. However, the abundance of zooplankton was not correlated with the content of other nutrients (nitrite, ammonia, dissolved inorganic nitrogen and orthophosphate) or environmental values (water temperature, salinity, rainfall, DO and pH). There was, however, a negative correlation with silicate (r=-0.583, P<0.5).

DISCUSSION

Hydrographical conditions and nutrient contents

The ecology of planktonic communities can describe the effect of a shallow water body on species composition, biodiversity and abundance (Rodrigo *et al*., 2003; Froneman, 2004; Morgado *et al*, 2007). The environmental factors fluctuated slightly within narrow ranges. The important factors were: shallow depth (< 10m), strong coastal wind and mixed tidal current that affected both horizontal and vertical water column mixing in the Gulf of Thailand (Nasir *et al*., 1999). Moreover, the rainfall data showed a clear trend that related to monsoon seasons and also affected salinity for more than seven months in this area. Salinity

Table 3 Correlation coefficients (r) for the relationships between hydrographic conditions, nutrients and plankton abundance; * P<0.05.

Parameter	Chlorophyll a	Phytoplankton	Zooplankton
Water temperature (°C)	0.511*	-0.287	0.173
Salinity (psu)	-0.557*	-0.005	-0.381*
Dissolved oxygen (mg l^{-1})	-0.147	0.708*	0.303*
pH	-0.272	0.529*	0.182
Rainfall (mm)	0.454*	-0.249	-0.009
NO^-_2 (mg l^{-1})	0.141	0.537*	-0.014
NO^-_3 (mg l^{-1})	-0.052	-0.014	0.426*
NH_3 (mg l^{-1})	0.305*	-0.278	0.095
DIN (mg l^{-1})	0.312*	-0.219	0.183
PO^{3-}_4 (mg l^{-1})	0.002	-0.271	-0.084
SiO^{3-}_4 (mg l^{-1})	-0.293	-0.431*	-0.583*
Chlorophyll a (mg m^{-3})	-	-0.019	0.619*

values seemed to be relatively stable from November to April during the northeast monsoon to summer months and were lowest in July and September during the southwest monsoon. Water temperature was fairly constant throughout the year, but its lowest value was recorded in January or February during the northeast monsoon. These data revealed a clear trend in seasonal variation of precipitation and salinity while water temperature varied only slightly. These characteristics are generally apparent in tropical coastal water (Robinson, 1963; Snidvongs and Sojisuporn, 1999; Castro and Huber, 2008). Dissolved oxygen and pH fluctuated temporally within normal, Thai, standard levels of seawater (Department of Pollutant Control, 2006).

Nutrient loading in coastal waters is generally influenced by freshwater runoff from the land and the availability of these nutrients in the water column (Dame and Allen, 1996; Philippart *et al*., 2000; McQuatters-Gollop *et al*., 2007). In a semi-enclosed bay, tidal current seems to be a major transporter for exchanges between the coastal water and the open sea. However, there is no detailed information to understand the effect that nutrient enrichment had on this bay. Dissolved nutrient contents fluctuated temporally with no noticeable trend with monsoon seasons, with the exception of the chlorophyll a concentration, which showed two high peaks in both monsoon seasons and could be considered as an enrichment factor for the bay. In shallow coastal water, the primary production of phytoplankton (chlorophyll a concentration) is generally related to nutrient content in the water column (Bot and Colijn, 1996; McQuatters-Gollop *et al*., 2007). This result showed a low average value of chlorophyll a concentration (1.30 ± 0.67 mg m^{-3}) during the sampling period and based on this, the area was assumed to be an oligotrophic coastal water (U.S. EPA, 2003; Calbet and Landry, 2004). Additionally, other nutrient values were at a normal level for Thai standard levels of seawater suitable for a conservation area (Department of Pollutant Control, 2006).

Plankton Community

Phytoplankton

In this semi-enclosed shallow bay, the seasonal patterns of phytoplankton composition and abundance tended to fluctuate slightly. The variability resulted from the interaction of hydrographic conditions and was less dependent on nutrient content during the two monsoons. This was probably due to the well-mixed water column and no freshwater runoff into the bay (Nasir *et al*., 1999). However, the average abundance during summer was lower than in both monsoon seasons. This can be explained by nutrient limitations such as nitrogen or silicate and also the slight coastal tidal currents (Smyda, 1983; Turner *et al*., 1998; Wu and Chou, 2003; Howarth and Marino, 2006). The period from March to April had no heavy turbulence in the water column so nutrients were not stirred up from the bottom to the surface water and thus might have been limiting for phytoplankton growth (Robinson, 1963; Karl *et al*., 1998; Boonyapiwat, 1999; Snidvongs and Sojisuporn, 1999).

Various data obtained for several regions in the Gulf of Thailand indicated that the species composition of phytoplankton did not differ between the southwest and northeast monsoon seasons (Boonyapiwat, 1999; Panchote, 2005; Boondao, 2006; Patarajinda *et al*., 2007). The marked trend showed that a characteristic phytoplankton composition of diatoms was the major contributor to the phytoplankton community in the Gulf of Thailand. However, the proportions of other groups varied by sampling area (Pienpichit, 1999; Tienpisut, 2007). The important factors were salinity and nutrient loading. However, in terms of abundance, there was temporal variation in some areas such as the estuaries or coastal zones affected by the nutrient loading or freshwater runoff during monsoon seasons (Thongbor, 2004; Boondao, 2006; Patarajinda *et al*., 2007).

Zooplankton

The dominant group of zooplankton was the copepods, which had the highest abundance over the sampling period. This result agreed with previous findings by Sribyatta (1996), Jivaluk (1999), Panchote (2005), Boondao (2006) and Srinui (2007) in the Gulf of Thailand. Long-term monitoring of the composition and abundance of zooplankton by Sribyatta (1996) found that the seasonal patterns were not different between the southwest and northeast monsoons in the upper western coast of the Gulf of Thailand. In this regard, a maximum abundance was recorded in July and a minimum value in March with data obtained from a 330 mm mesh size plankton net.

Different mesh sizes in sampling equipment influence the composition and abundance of zooplankton (Munk *et al*., 2003; Punnarak, 2004; Jitchum and Wongrat, 2007). The result from the current study, using a 200 μm plankton net, showed a high proportion of copepodid larvae and other meroplankton, with the average maximum abundance being recorded during summer (Figure 3b). This result indicated that in this study area, summer was a high reproductive period for marine organisms, especially copepods and bivalves. It can be explained by the warmer summer months increasing the breeding rate of marine organisms (Poulet *et al*., 1995; Froneman, 2004; Hooff & Peterson, 2006; Castro and Huber, 2008). Also, marine larvae and micro-zooplankton are assumed to be the main consumers of phytoplankton in tropical waters (Landry *et al*., 1995; Calbet and Landry, 2004; Calbet, 2008). Therefore, these results showed an increase in average zooplankton abundance with a decrease in average phytoplankton abundance during the summer period.

Hydrographical conditions, nutrients and plankton community

Relationships between hydrographic variability and nutrients with phytoplankton and zooplankton abundance varying with monsoon seasons were not clearly demonstrated. This can be explained by the well-mixed tidal currents and no freshwater discharges in this bay. All parameters fluctuated slightly within narrow ranges over the sampling period, indicating that the fairly constant conditions in this semi-enclosed bay are probably due to the small scale variability (Munk *et al*., 2003; Rodrigo *et al*., 2003). Moreover, it was difficult to compare data with previous reports by Thongbor (2004), Boondao (2006), and Permsirivanich (2007) because they were based on different sampling equipment and techniques, as well as these studies only covering restricted areas in the Gulf of Thailand.

Phytoplankton abundance showed a positive correlation with nitrite, dissolved oxygen and pH but was negatively correlated to silicate. In this regard, diatoms formed the majority phytoplankton composition and use silicate when forming their silica shells. Hence, when phytoplankton abundance increased, silicate decreased (Turner, *et al*., 1998; Wu and Chou, 2003). In addition, the ratio of silicate to dissolved inorganic nitrogen was greater than 1:1, making conditions appropriate for marine diatom growth and also potentially controlling the coastal phytoplankton community (Karl *et al*., 1998; Turner *et al*., 1998). However, zooplankton abundance showed a positive correlation to chlorophyll a concentration, nitrate and dissolved oxygen but was negatively correlated to silicate and salinity. In this regard, these results normally occur in tropical trophic structures (Calbet and Landry, 1999; Calbet 2001; Calbet, 2008).

One implication from this study was that the chlorophyll a concentration represented primary production in the water column that was positively correlated to water temperature, rainfall, nitrate and dissolved inorganic nitrogen but negatively correlated to salinity. These results demonstrated clear relationships between environmental parameters and primary production and also that water temperature, salinity and rainfall were influenced by monsoon seasons (Robinson, 1963; Snidvongs and Sojisuporn, 1999). Moreover, it supported the hypothesis that dissolved inorganic nitrogen was an important factor for phytoplankton growth in oligotrophic coastal waters (Bot and Colijn, 1996; Karl *et al*., 1998; Philippart *et al*., 2000; Howarth and Marino, 2006). This finding suggested that chlorophyll a concentration could be a better indicator for enrichment determination and correlation with environmental variability than phytoplankton abundance. In addition, chlorophyll a concentration represented almost all phytoplankton composition in the water column but phytoplankton abundance is based on only larger cells (> 20 µm) (Bot and Colijn, 1996; McQuatters-Gollop *et al*., 2007).

In this bay, it was clear that low productivity was not affected by human activities. Moreover, the nutrient content showed suitable values for a conservation area based on Thai, standard levels of seawater (Department of Pollutant Control, 2006). Accordingly, there was no evidence of expected species composition changes and abundance increases due to increased nutrients . In addition, the shift in the main species composition from diatoms to dinoflagellates or blue-green algae was not recorded. These results revealed that a small shallow bay could be isolated from adjacent areas, and in this regard, the plankton community was highly homogenous throughout the annual cycle.

CONCLUSION

The plankton community in Manao Bay showed no significant seasonal variation in composition and abundance during two monsoon seasons. The bay was characterized as an oligotrophic coastal water with slight fluctuations in the hydrographic conditions and nutrients. Primary production was influenced by: water temperature, rainfall, salinity, silicate and dissolved inorganic nitrogen. The dominant groups of phytoplankton were: centric diatoms (e.g. *Rhizosolenia*, *Chaetoceros, Bacteriastrum*) and pennate diatoms (e.g. *Pleurosigma*, *Thalassionema*, *Nitzschia*), while copepods and meroplankton were the major contributors to zooplankton. These characteristics represent the fundamental components of a plankton community in tropical oligotrophic coastal waters.

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