

Distribution of coccolithophorids and coccoliths in surface ocean off northeastern Taiwan

Tien-Nan Yang^{1,3}, Kuo-Yen Wei^{1,*}, and Gwo-Ching Gong²

¹Global Change Research Center and Department of Geosciences, National Taiwan University, Taipei, 10716 Taiwan, ROC

²Department of Oceanography, National Taiwan Ocean University, Keelung, Taiwan, ROC

(Received October 27, 2000; Accepted July 26, 2001)

Abstract. This study depicts quantitatively the distribution of coccolithophorids and coccoliths during one summer season in the area off northeastern Taiwan where the Kuroshio flows northward and interacts with the shelf waters of the East China Sea. To minimize the influence of diurnal variation of coccolithophorids, only samples taken at sunrise were analyzed. Sea-surface water (2 m in depth) samples were obtained at six stations during the summer of 1996. Forty-one species were identified with *Emiliania huxleyi* (Lohmann) Hay et Mohler, *Palusphaera vandellii* Lecal emend. R. E. Norris, *Umbellosphaera* Paasche spp. and *Syracosphaera* Lohmann spp. being the predominant forms. Three coccolithophorid communities were recognized: (1) the continental shelf community, dominated by *Emiliania huxleyi*, *Gephyrocapsa oceanica* Kamptner and *Calcosolenia murrayi* Gran, which showed intermediate biodiversity and species evenness; (2) the Kuroshio community, which showed the highest diversity and evenness, with a flora dominated by genus *Umbellosphaera* Paasche; and (3) the Western North Pacific Central Water community, which had the lowest diversity and evenness, with dominant species *Calicasphaera* Kleijne and *Palusphaera vandellii*. The absolute abundance of loose coccoliths ranged from 10.2×10^4 individual coccoliths l⁻¹ to 22.9×10^4 individual coccoliths l⁻¹, while those of coccospheres were much less, ranging from 11.5×10^3 cells l⁻¹ to 19.7×10^3 cells l⁻¹. The largest absolute abundance of coccoliths and coccospheres was found in the Kuroshio path.

Keywords: Coccolithophorid; Diversity; East China Sea; Kuroshio; Standing crops.

Introduction

Coccolithophorids are unicellular, marine, golden-brown algae (Haptophyta) commonly found in near-surface waters in patchy distributions. They are one of the world's major primary producers, contributing about 15 per cent of the average oceanic phytoplankton biomass to the oceans (Berger, 1976). They also produce elaborate, minute calcite platelets (coccoliths), covering the cell to form a coccosphere and supplying up to 60 per cent of the bulk pelagic calcite deposited on the sea floors (Honjo, 1996). Coccoliths can reflect the visible light from surface water during coccolithophorid bloom season (Holligan et al., 1983; Groom and Holligan, 1987; Balch et al., 1991) and thus enhance albedo. Coccolithophorids, therefore, have recently gained much attention as important players in global climate change and carbon cycles (Westbroek et al., 1993 and references therein; Hagino et al., 2000; Cortés et al., 2001; Haidar and Thierstein, 2001).

The large-scale distribution of modern coccolithophorids in the open ocean has been studied in various

parts of the world (for review, see Winter et al., 1994 and references therein). About two decades ago, Okada and Honjo (1970; 1973) and Nishida (1979) completed large-scale studies concerning coccolithophorid biogeography in the Pacific Ocean, with emphasis on the North Pacific. Okada and Honjo (1973) established six coccolithophorid zones in the surface water along the 155°W meridian based on the distribution pattern of characteristic species. Recently, Hagino et al. (2000) documented the spatial dynamics of coccolithophorid assemblages in the Western-Central Equatorial Pacific Ocean, while Cortés et al. (2001) studied the temporal variation pattern of coccolithophorid ecology in water column at the HOT station ALOHA, Hawaii. For the western boundary constraint of the Pacific, Okada and Honjo (1975) conducted a large-scale study of coccolithophorid biogeography of the western Pacific marginal seas. Nevertheless, few detailed analyses of living coccolithophorids of individual marginal seas and biogeographic provinces of the western Pacific have appeared. The present study focuses particularly on the community structure of coccolithophorids in the surface waters (~2 m in depth, hereafter defined as the surface water) of summer-season in the area offshore of northeastern Taiwan, where the northward flowing Kuroshio encounters the Ryukyu Ridge, collides with the continental shelf break, and then deflects to the northeast (Nitani, 1972).

³E-mail: f4224103@ms.cc.ntu.edu.tw

*Corresponding author. Tel: +886-2-23691143; Fax: +886-2-23636095; E-mail: weiky@ms.cc.ntu.edu.tw



The Kuroshio, which originates from the North Equatorial Current, is a strong western boundary current that flows northward along the eastern coast of Taiwan and turns northeastward as it enters the Okinawa Trough (Figure 1). As the Kuroshio impinges on the shelf break northeast of Taiwan, some of the surface water intrudes onto the shelf forming a Branch Current (Qiu and Imasato, 1990; Hsueh et al., 1992; Tang et al., 2000) and some of the subsurface water forms a countercurrent hugging the slope (Chung et al., 1993). It has been long observed that the main stream of the Kuroshio shifts its path seasonally: during winter the current path is closer to the shelf break and for the rest of the year the current path shifts seaward (Sun, 1987; Chao, 1991; Tang and Yang, 1993; Tang et al., 2000). The Kuroshio is characterized by high sea-surface temperature and salinity year-round, while the southern East China Sea (ECS) shelf water is saltier and colder during the cold season, and *vice versa* in the warm season. In July 1996, when our field investigation was conducted, the area of the Kuroshio and the Western North Pacific Central (WNPC) (coined by Sverdrup et al., 1942) water was blanketed with extensive warm surface

water, and a cold eddy off northeast Taiwan was also observed from the NOAA/AVHRR imagery of sea surface temperature (Fig. 2c in Tseng et al., 2000).

The physical forcing in turn controls the chemical hydrography, as Gong et al. (1997) documented that retreat of the Kuroshio intrusion from the shelf northeast of Taiwan restored the upwelling center, which resulted in a doubling of the phytoplankton biomass around the cyclonic eddy within two weeks. In contrast with the sophisticated and variable nutrient conditions of the shelf water, the Kuroshio main stream has been more static with lower nutrient contents (Gong et al., 1997; Gong et al., 2000; Liu et al., 2000). However, the hydrographic structures of the southern ECS during the summer are more complicated than in the winter, because the Kuroshio and shelf waters coexist on the shelf break off northeast of Taiwan during the summer (Lie et al., 1998).

Materials and Methods

Hydrographic Data

Temperature and salinity measurements were obtained from sensors loaded on the Seabird CTD-General Oceanic Rosette assembly during the sampling period. Water samples for nutrients measurements were stored in 100 ml polypropylene bottles and frozen immediately with liquid nitrogen. Nitrate was analyzed with a self-designed flow injection analyzer and was reduced to nitrite with a cadmium wire, activated with a copper sulfate solution (Gong, 1992). The precision for the nitrate analysis was 0.3 μM for concentrations of 10 μM or higher.

Coccolithophorid Sample Processing

Sea surface water (~2 m in water depth) samples for coccolithophorid works were taken from more than 30 stations in the area off northeastern Taiwan during Cruise 457 of the R/V *Ocean Research I* in the summer of 1996 (July 15 through 22). A Seabird CTD-General Oceanic Rosette assembly with 12 Go-Flo bottles (volume of 10 L) was used to obtain seawater samples.

Seawater (about 1–2 L) obtained by the Go-Flo bottles was filtered on board through a Nuclepore® polycarbonate membrane (47 mm in diameter, pore size 0.4 μm) by applying low-pressure (<100 mm Hg) generated by a vacuum pump. Each membrane with its filtered particles was immediately transferred into a plastic Petri-dish and refrigerated for preservation. Upon returning to the laboratory, Petri-dishes containing membranes were put into a desiccator. A piece of membrane, about 1 cm^2 , was cut and mounted onto an aluminum stub with double-sided tape and was then coated with platinum using a HITACHI E101 ion sputter coater.

To minimize the effects of diurnal variation (Figuerola et al., 1998; Graham et al., 2000), only the six samples taken during sunrise were used for the study. Two Stations, St. 6 and St. 24, were located at the continental shelf and the WNPC water, respectively, while the others, St. 12, St. 17,

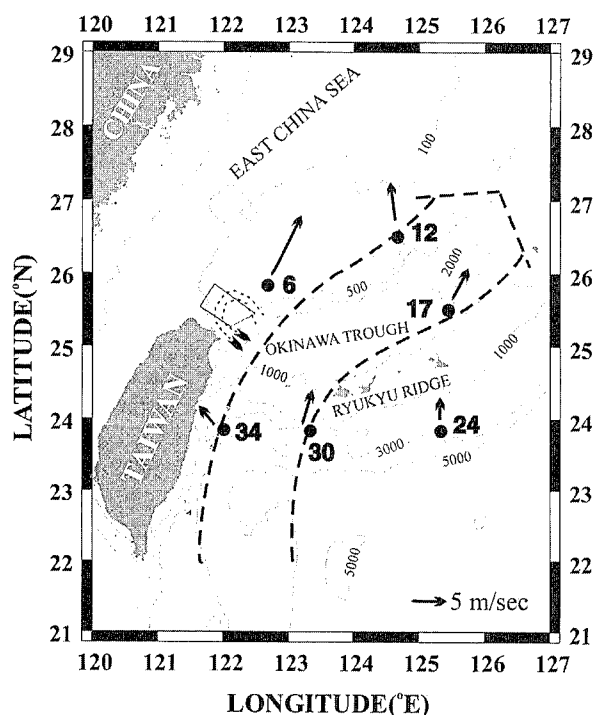


Figure 1. Location of sampling stations (solid dots) in the area off northeastern Taiwan. Sea surface waters (~2 m in depth) were collected during summer 1996. Stations 12 and 34, and 17 and 30 are located within the flow path of Kuroshio (depicted by dashed big arrow). Stations 6 and 24 are located at continental shelf of the southern ECS and the WNPC water, respectively. The solid arrow at each station represents the wind direction, and its length represents the relative wind speed during the sampling time. Two parallel dashed arrows delineate the countercurrent existing on the continental shelf off the northern tip of Taiwan (Tang et al., 2000). The closed solid polygon around the countercurrent indicates the upwelling area. Depth contour lines are in meters.

St. 30 and St. 34 were located within the path of the Kuroshio main stream.

Counting Procedure

The coccoliths and coccospheres on the cut membrane portion were examined in horizontal rows and counted in a total of 320 randomly picked viewing fields under 2000 × magnification with a HITACHI S-2400 Scanning Electron Microscope (SEM). In addition, several other fields were examined for rare species.

The formula for estimating the abundance/standing crop of coccoliths/coccospheres per liter of seawater is as follows:

$$N_T = N_C \times 925 / S_v,$$

where N_T is the number of total individuals of coccoliths or of coccospheres per liter, N_C is the number of coccoliths or of coccospheres counted in 320 viewing fields, S_v is the filtered volume of seawater, and the value 925 is a ratio constant of the area covered by particles on the membrane ($9.62 \times 10^{-4} \text{ m}^2$, diameter 35 mm) to that of the 320 fields examined (the length and width of each field under 2000 × magnification is about 65 μm and 50 μm, respectively). The ratio constant was derived as $925 = 9.62 \times 10^{-4} \text{ m}^2 / 320 \times 3.25 \times 10^{-9} \text{ m}^2$.

Taxonomy

The systematic classification of coccolithophorids is based mainly on the morphology of cells and coccoliths. The identification of the coccolithophorid species was conducted following the taxonomic classification scheme outlined by Jordan and Green (1994 and references therein). Some associations of holococcolith-heterococcolith or holococcolith-holococcolith coccospheres were documented by Cros et al. (2000). For reviews, see Cros et al. (2000) and references therein. In this study we also adopted the nomenclatural taxonomy for those combinations made by Cros et al. (2000). The coccolithophorid taxa tallied are listed in Table 1. The individuals of coccolithophorids counted in 320 fields are presented in Appendix A. In total 41 coccolithophorid species were identified with the addition of one genus of coccolith and one genus of coccosphere.

SEM photographs of selected species, including major dominant forms, are shown in Plates I-IV. Other rare species encountered both in counting and extra examining will be presented elsewhere. Holococcolithophorid species are displayed in Plate I, and II (Figures 1-4), while other heterococcolithophorid species are shown in Plates II (Figures 5-8), III and IV.

Results

Hydrography

In July 1996, the hydrological parameters in the surface water (~2 m in depth) of the six stations were recorded at dawn. The temperature values in surface water showed no difference (ca. $30.1 \pm 0.2^\circ\text{C}$) around the area off

northeastern Taiwan except for St. 6, located at the continental shelf, which was affected by an upwelling from the subsurface water of Kuroshio and had the lowest value of 28.6°C . The phenomenon in the same month, of a warm area covering the Kuroshio path and WNPC water and of a cold eddy off northeastern Taiwan, were also documented from the NOAA/AVHRR sea surface temperature image (Fig. 2c in Tseng et al., 2000). While the values of salinity fell almost in the same range around $34.0 \pm 0.2\text{‰}$, the wind velocities ranged from 3 to 10 m per

Table 1. Species list of tallied coccolithophorid taxa recognized in this study.

<i>Acanthoica quattropsina</i> Lohmann, 1937 ^a
<i>Anoplosolenia brasiliensis</i> (Lohmann) Deflandre, 1952
<i>Calciopappus rigidus</i> Heimdal, 1981
<i>Calciosolenia murrayi</i> Gran, 1912
<i>Calicasphaera blokii</i> Kleijne, 1991
<i>C. diconstricta</i> Kleijne, 1991
<i>Calyptrolithina divergens</i> (Halldal et Markali) Heimal, 1982
<i>C. multipora</i> (Gaarder) R.E. Norris, 1985
<i>C. wettsteinii</i> (kamptner) Kleijne, 1991
<i>Calyptrolithophora papillifera</i> Heimdal, 1980
<i>Calyptrosphaera oblonga</i> Lohmann, 1902
<i>Ceratolithus cristatus</i> Kamptner, 1950 ^b
<i>Corisphaera gracilis</i> Kamptner, 1937
<i>Cyrtosphaera lecaliae</i> Kleijne, 1992
<i>Daktylethra</i> sp. Gartner, 1969
<i>Discosphaera tubifera</i> (Murray et Blackman) Ostenfeld, 1900
<i>Emiliania huxleyi</i> (Lohmann) Hay et Mohler, 1967
<i>Gephyrocapsa ericsonii</i> McIntyre et Bé, 1967
<i>G. oceanica</i> Kamptner, 1943
<i>Homozygosphaera spinosa</i> (Kamptner) Deflandre, 1952
<i>H. triarcha</i> Halldal et Markali, 1955
<i>Michaelsarsia adriaticus</i> (Schiller) Manton et al., 1984
<i>Ophiaster hydroideus</i> (Lohmann) Lohmann, emend. Manton et Oates, 1983
<i>O. reductus</i> Manton et Oates, 1983
<i>Palusphaera vandellii</i> Lecal, emend. R.E. Norris, 1984
<i>Poricalyptra magnaghii</i> (Borsetti et Cati) Kleijne, 1991
<i>Rhabdosphaera clavigera</i> Murray et Blackman, 1898
<i>Sphaerocalyptra quadridentata</i> (Schiller) Deflandre, 1952
<i>Syracolithus catilliferus</i> (Kamptner) Deflandre, 1952
<i>Syracosphaera dilatata</i> Jordan et al., 1993
<i>S. exigua</i> Okada et McIntyre, 1977
<i>S. halldalii</i> Jordan et Green, 1994
<i>S. molischii</i> Schiller, 1925
<i>S. nodosa</i> Kamptner, 1942 ^c
<i>S. orbiculus</i> Okada et McIntyre, 1977
<i>S. pirus</i> Hallda et Markali, 1955
<i>S. prolongata</i> Gran ex Lohmann, 1913
<i>S. pulchra</i> Lohmann, 1902
<i>S. rotula</i> Okada et McIntyre, 1977
<i>Umbellosphaera irregularis</i> Paasche, 1955
<i>U. tenuis</i> (Kamptner) Paasche, 1955
<i>Umbilicosphaera hulburtiana</i> Gaarder, 1974

^aAn association species reported by Lecal-Schlauder (1961) and Cros et al. (2000).

^bAn association species reported by Alcober and Jordan (1997), Young et al. (1998) and Cros et al. (2000).

^cAn association species reported by Kamptner (1941) and Cros et al. (2000).



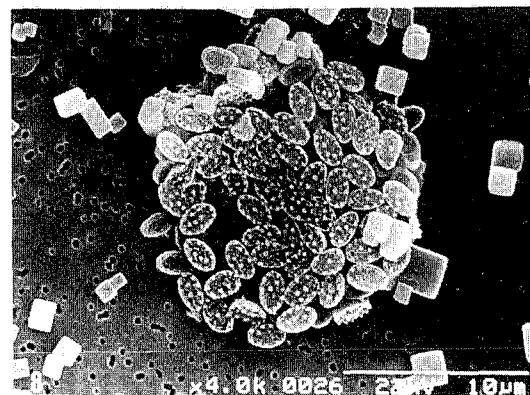
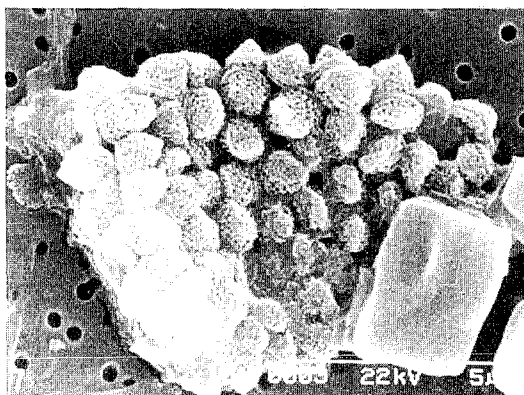
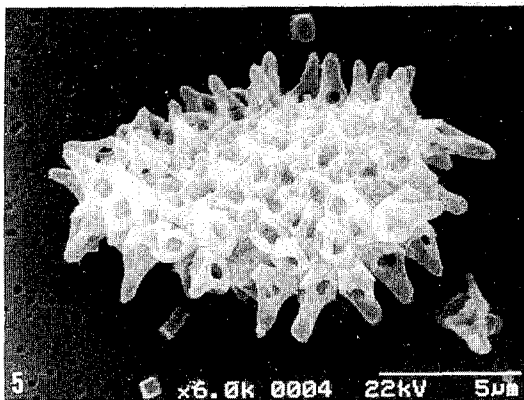
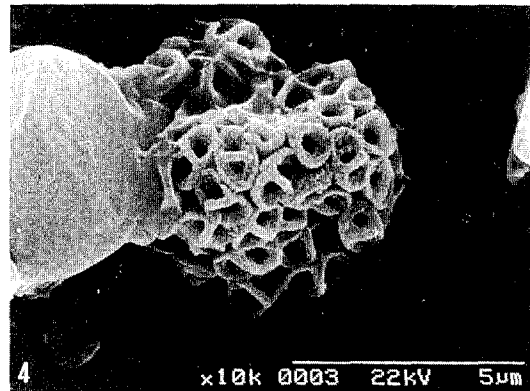
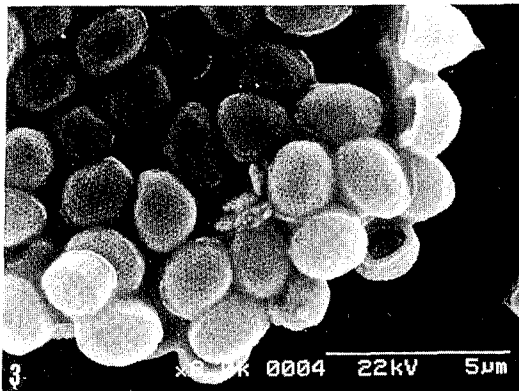
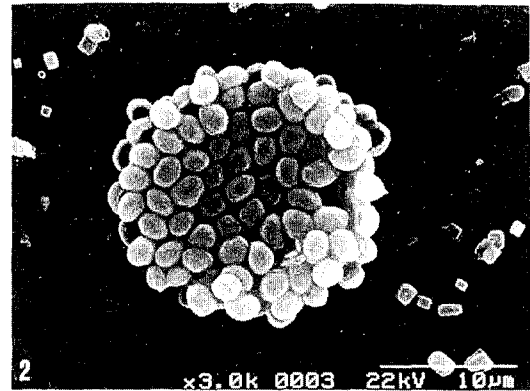
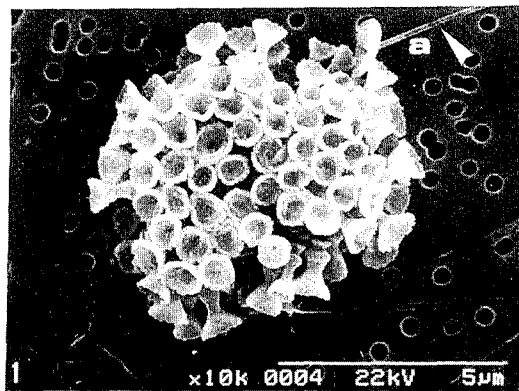
Appendix A. List of individuals of coccolithophorid counted in 320 fields of each taxon recognized in samples recovered from the surface waters (2 m in depth) of Stations 6, 12, 17, 24, 30 and 34. The raw data in first and second columns below each station represent the number of coccospheres and coccoliths, respectively, encountered in the fixed fields. Numbers in bold indicate in total the maximum abundance among the six stations whereas those underlined mark the minima.

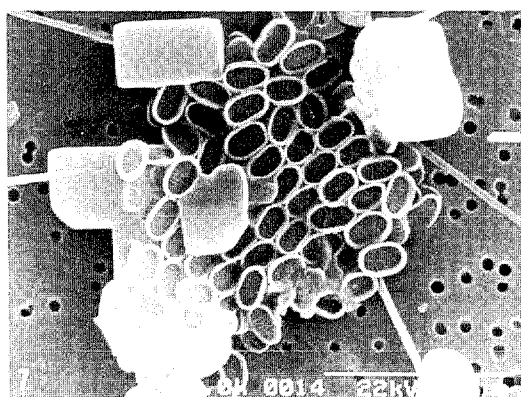
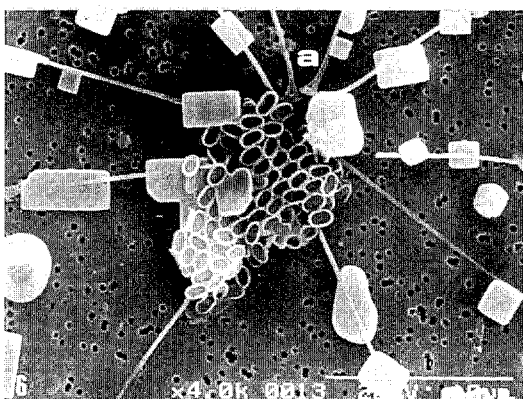
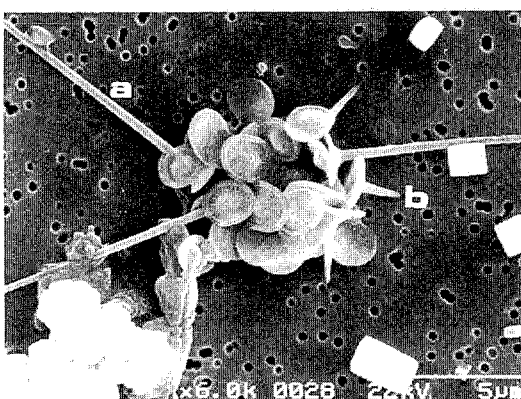
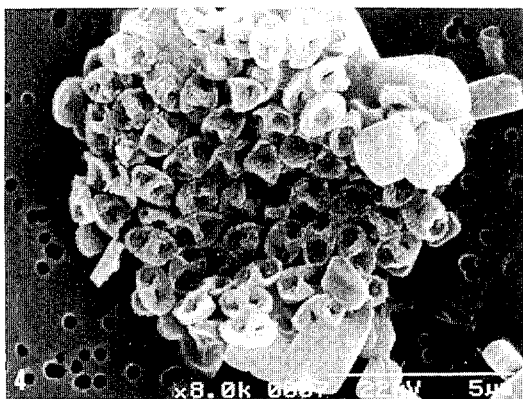
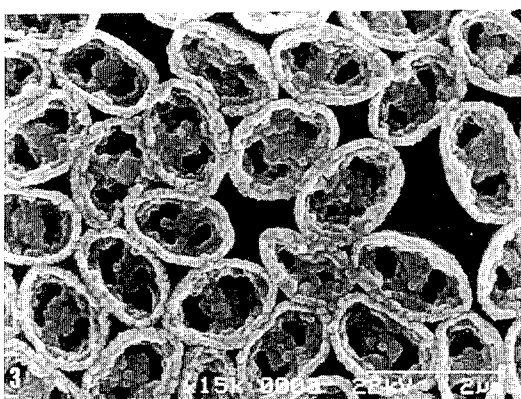
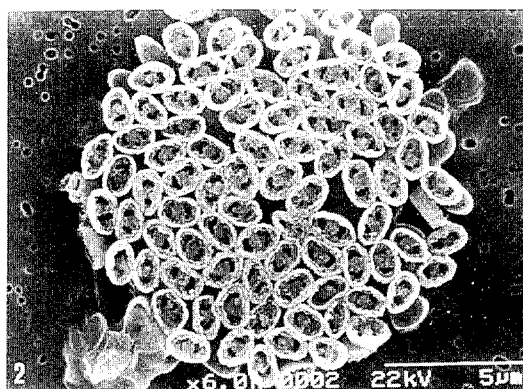
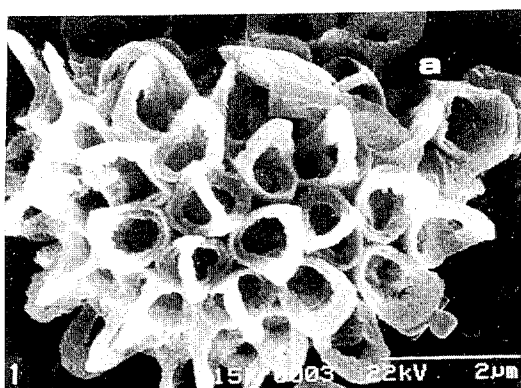
Taxa category	St. 6	St. 12	St. 17	St. 24	St. 30	St. 34
<i>Acanthoica quattropsina</i>	0 0	1 0	0 0	1 2	1 0	0 0
<i>Anoplosolenia brasiliensis</i>	0 0	0 0	0 0	0 0	0 0	1 2
<i>Calciopappus rigidus</i>	6 0	0 0	0 0	0 0	0 0	0 0
<i>Calciosolenia murrayi</i>	1 23	0 16	1 5	0 13	0 2	2 15
<i>Calicasphaera blokii</i>	0 0	2 0	3 0	0 0	0 0	0 0
<i>C. diconstricta</i>	0 0	0 0	0 0	8 0	0 0	0 0
<i>Calyptrolithina divergens</i>	5 2	0 0	0 0	0 1	0 0	0 0
<i>C. multipora</i>	0 0	0 0	0 1	0 0	0 0	0 0
<i>C. wettsteinii</i>	0 0	0 0	0 0	0 0	0 0	1 0
<i>Calyptrolithophora papillifera</i>	0 0	2 0	0 0	0 0	0 0	0 0
<i>Calyptrosphaera oblonga</i>	0 0	1 0	0 0	0 0	0 0	0 0
<i>Ceratolithus cristatus</i>	0 0	0 0	0 1	0 0	0 2	0 0
<i>Corisphaera gracilis</i>	2 12	1 12	0 1	1 8	0 1	0 0
<i>C. sp.</i>	0 0	0 0	0 0	0 0	0 0	1 1
<i>Cyrtosphaera lecaliae</i>	0 0	0 0	0 0	0 0	0 0	1 0
<i>Dakylethra sp.</i>	0 0	0 0	0 0	0 0	0 0	1 12
<i>Discosphaera tubifera</i>	0 2	1 5	2 29	0 14	1 12	2 26
<i>Emiliana huxleyi</i>	3 91	4 110	1 36	0 15	0 27	3 14
<i>Gephyrocapsa ericsonii</i>	0 0	1 0	0 0	0 0	0 0	0 1
<i>G. oceanica</i>	1 25	2 15	3 20	0 6	1 5	2 12
<i>Homozygosphaera spinosa</i>	0 0	0 0	0 0	0 0	1 0	0 0
<i>H. triarcha</i>	0 0	0 0	0 0	0 0	1 0	0 0
<i>Michaelsarsia adriaticus</i>	0 0	0 19	0 0	0 0	0 0	0 0
<i>Ophiaster hydroideus</i>	2 0	0 0	1 0	0 0	1 0	0 0
<i>O. reductus</i>	0 0	2 0	0 0	0 0	1 35	1 0
<i>Palusphaera vandellii</i>	0 11	1 194	6 94	7 267	7 116	2 73
<i>Poricalyptra magnaghii</i>	1 0	0 0	0 0	0 0	1 0	0 0
<i>Rhabdosphaera clavigera</i>	0 0	0 0	0 4	0 2	0 2	0 0
<i>Sphaerocalyptra quadridentata</i>	0 0	0 0	0 0	0 0	0 0	2 0
<i>Syracolithus catilliferus</i>	0 0	0 0	1 0	0 0	0 0	0 0
<i>Syracosphaera dilatata</i>	0 0	2 1	0 0	0 0	0 1	0 0
<i>S. exigua</i>	0 0	0 0	0 12	1 5	1 16	0 0
<i>S. halldalii</i>	0 0	6 1	2 31	7 59	3 16	2 0
<i>S. molischii</i>	1 0	0 0	0 0	0 0	0 0	0 0
<i>S. nodosa</i>	0 0	0 1	0 2	3 6	2 2	1 0
<i>S. orbiculus</i>	4 0	2 0	0 0	0 0	0 0	0 0
<i>S. pirus</i>	0 0	0 0	0 1	0 0	0 0	0 0
<i>S. prolongata</i>	1 5	1 4	1 8	0 22	1 4	0 1
<i>S. pulchra</i>	0 0	0 9	0 5	0 1	0 4	0 9
<i>S. rotula</i>	0 0	0 0	0 0	1 1	1 1	1 0
<i>S. spp.</i>	1 5	5 21	3 17	0 5	0 23	1 32
<i>Umbellosphaera irregularis</i>	1 3	1 7	3 68	1 19	1 19	8 102
<i>U. tenuis</i>	0 14	6 84	6 137	1 30	2 84	5 178
<i>Umbilicosphaera hultburtiana</i>	0 0	0 0	0 0	0 0	1 0	0 0
Miscellaneous	4 27	7 55	2 22	6 58	1 41	4 17
Total individuals	33 <u>220</u>	48 554	35 494	37 534	<u>28</u> 413	41 495



Plate I. Pictures exhibited are all holococcolithophorid species. 1, *Calicasphaera diconstricta* Kleijne. Monomorphic coccosphere with lateral view of calicaliths with two constrictions and distal view of calicaliths showing the central opening. a: A *Palusphaera vandellii* rhabdolith with styliform process (arrow). (St. 17); 2, *Calyptrosphaera dentata* Kleijne. Monomorphic coccosphere consisting of oval calypetroform holococcoliths. (St. 30); 3, *C. dentata* Kleijne. Magnified view of lower right corner of Figure 2 shows the detailed coccoliths with one tooth-like protrusion. (St. 30); 4, *Corisphaera gracilis* Kamptner. A small dimorphic coccosphere; only the body zygoliths are featured. (St. 12); 5, *Homozygosphaera triarcha* Halldal et Markali. Monomorphic coccosphere consisting of zygoliths with three arches. (St. 30); 6, *Poricalyptra magnaghii* (Borsetti et Cati) Kleijne. Dimorphic coccosphere with calypetroform body coccoliths and helladoform circum-flagellar coccoliths. (St. 30); 7, *Sphaerocalyptra* sp. Collapsed coccosphere showing only body calyptroliths of campanulate forms. (St. 17); 8, *Syracolithus* sp. type A. Kleijne. Disintegrated monomorphic coccosphere consisting of laminoliths. Cubics are minute salt crystals precipitated from seawater. (St. 17).







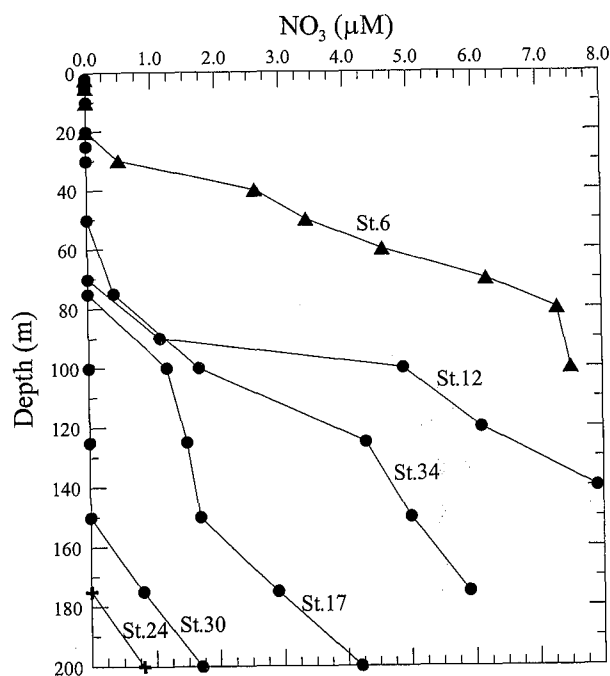


Figure 2. Vertical profiles of nitrate concentration at the studied six stations. The continental shelf Station (St. 6) is represented by ▲, the Kuroshio stations (St. 12, St. 17, St. 30 and St. 34) are represented by ●, and the WNPC station (St. 24) is presented by +.

second, with the highest speed at the shelf station St. 6 and the lowest at St. 24 in the WNPC water. The direction of water current in the investigated area was northward except at St. 34 (Figure 1).

The most important nutrients for coccolithophorids are nitrate and phosphate (Brand, 1994 and references therein). The vertical distributions of nitrate concentrations obtained in the six stations are plotted in Figure 2. The concentrations of nitrate in the top 20 m of seawater in the study area were too low to be detected. The nitracline in Station 6 was the shallowest while that at Station 24 was the deepest. Nitrate displays three distribution patterns in the water column around northeastern Taiwan: turbulent diffusion in shelf water, molecular diffusion in the relatively static WNPC water, and an intermediate mode in the Kuroshio path.

Coccolithophorid Diversity and Standing Crop

The species richness of coccoliths, coccospheres, and coccolithophorids recorded in the six stations are listed in Table 2 and drawn in Figure 3. More species abundance was found in the flow path of the Kuroshio, with the largest at St. 30. Furthermore, various diversity indices of the floral structure were calculated: Simpson's index (λ), Shannon's index (H) and the evenness index (E) (Table 2, Figure 4), following Simpson (1949), Shannon and Weaver

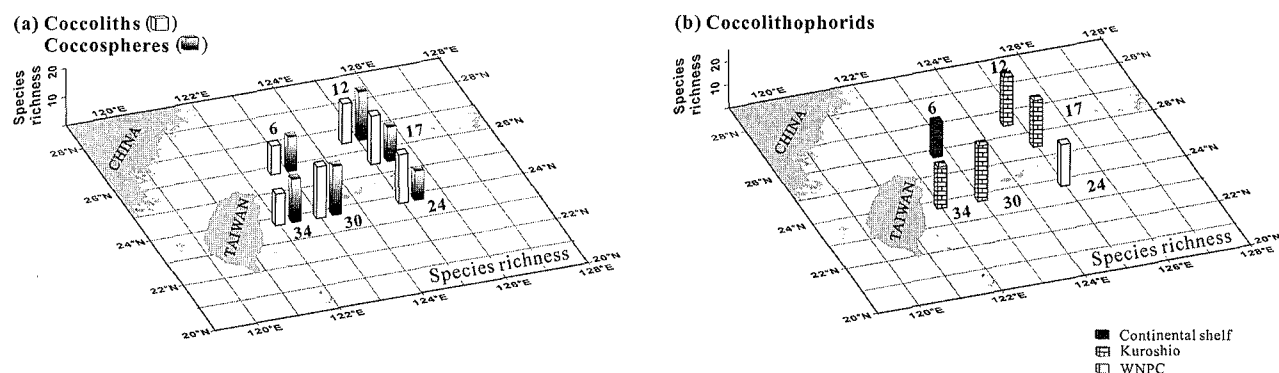


Figure 3. Plots of species richness of (a) coccoliths and coccospheres and (b) coccolithophorids in the studied area. The Kuroshio path has higher values of species richness. The seaward side of the path, Station 30, recorded the highest species richness. Values of species richness are listed in Table 2. The elevation of map in Figures 3-9 is about 30 degrees.

Plate II. Figures 1-4: holococcolithophorids; Figures 5-8: heterococcolithophorids. 1, *Syracosphaera nodosa* Kamptner. *Helladosphaera cornifera*, holococcolithophorid form of *Syracosphaera nodosa*. Dimorphic coccosphere consisting of helladoform circum-flagellar coccoliths (a) and zygoform body coccoliths. This species is recently recorded as part of a *Syracosphaera nodosa*-*Helladosphaera cornifera* combination by Cros et al. (2000), who suggested that *S. nodosa* has the priority over *H. cornifera*. (St. 17); 2, Unidentified sp. Disintegrated monomorphic coccosphere. (St. 24); 3, Unidentified sp. Magnified view of Figure 2 shows the irregular pore shape in the central area. (St. 24); 4, Unidentified sp. Collapsed monomorphic coccosphere; showing coccoliths with a robust bridge traversing the central area. (St. 17); 5, *Acanthoica quattropsina* Lohmann. Disintegrated ellipsoidal coccosphere with spines at both poles: a: two long apical spines at one pole and b: one long apical spine and three short apical spines at opposite pole. This species is recently recorded as part of an *Acanthoica quattropsina*-holococcolithophorid combination by Cros et al. (2000), who suggested that *Acanthoica quattropsina* has the priority. (St. 17); 6, *Calciopappus rigidus* Heimdal. Collapsed elongate coccosphere consisting of elliptical body coccoliths and long apical spines (a) around the flagellar area. (St. 17); 7, *C. rigidus* Heimdal. Magnified view of Figure 6 showing the elliptical body coccoliths. (St. 17); 8, *Calciosolenia murrayi* Gran. Disintegrated elongated coccosphere shows two terminal spines (a) and some rhombolith-type coccoliths (b). (St. 6).

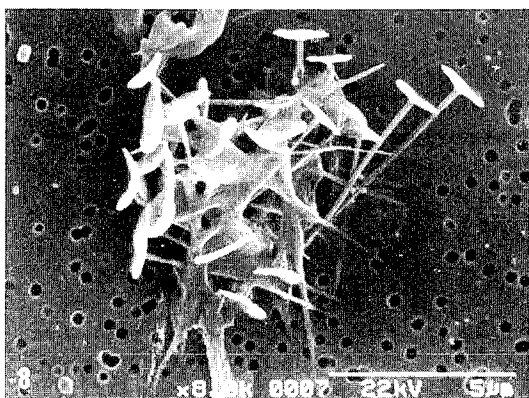
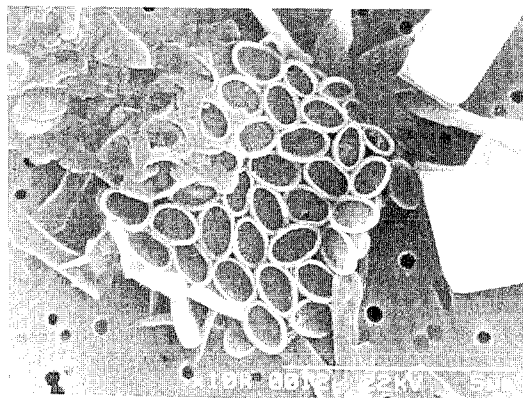
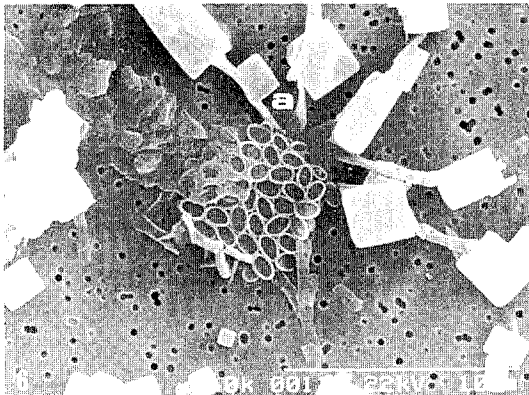
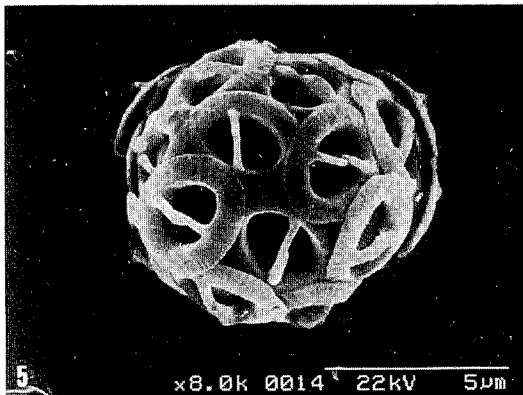
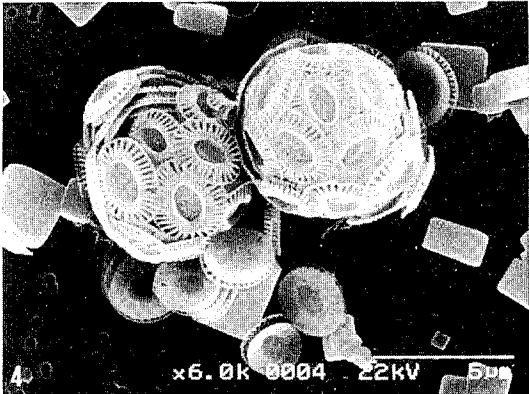
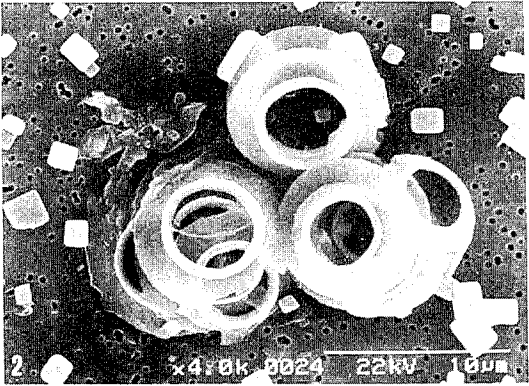


Table 2. Various diversity indices of coccoliths and coccospheres at the six investigated stations. Numbers in bold indicate maximum diversity whereas those underlined mark the minima.

Station	6	12	17	24	30	34
Coccolith						
Species richness	<u>10</u>	14	17	17	18	11
Simpson's index (λ)	0.268	0.235	0.163	<u>0.341</u>	0.174	0.219
1- λ	0.732	0.762	0.837	<u>0.659</u>	0.826	0.781
Shannon's index (H)	1.748	1.818	2.134	<u>1.699</u>	2.133	1.857
Evenness index	0.578	0.633	0.690	<u>0.432</u>	0.638	0.662
Coccosphere						
Species richness	12	17	12	<u>10</u>	17	15
Simpson's index (λ)	0.120	0.086	0.111	<u>0.184</u>	0.108	0.096
1- λ	0.880	0.914	0.889	<u>0.816</u>	0.892	0.904
Shannon's index (H)	2.319	2.655	2.361	<u>1.912</u>	2.567	2.630
Evenness index	0.800	0.801	0.833	0.768	<u>0.684</u>	0.734
Species richness of coccolithophorid	<u>15</u>	21	20	18	24	18

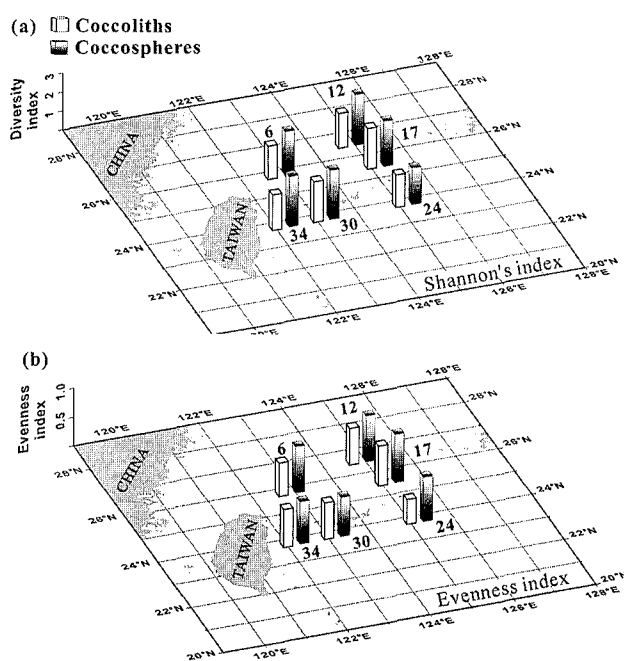
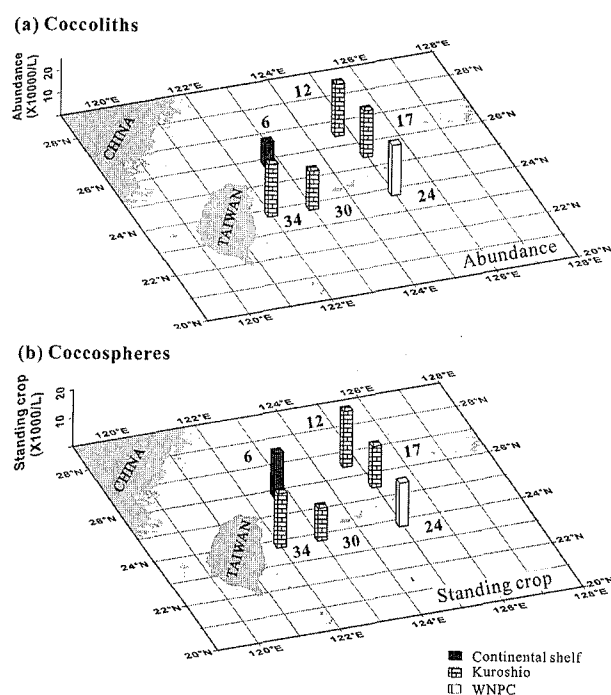
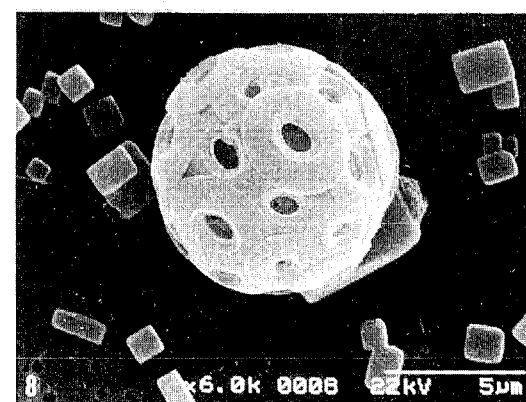
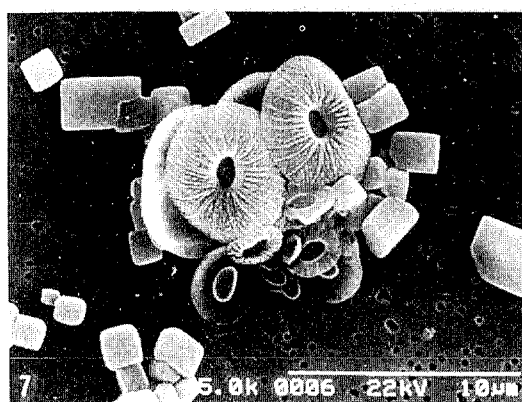
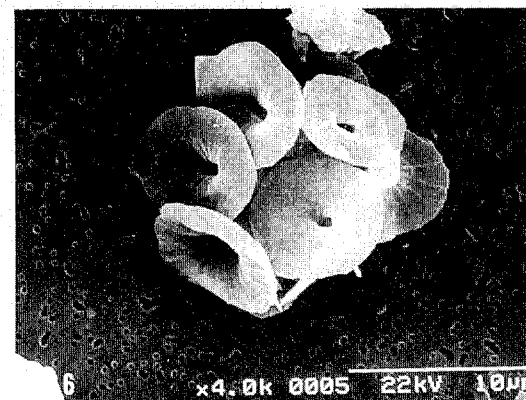
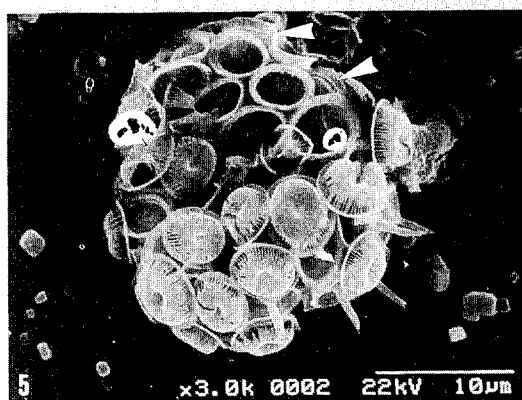
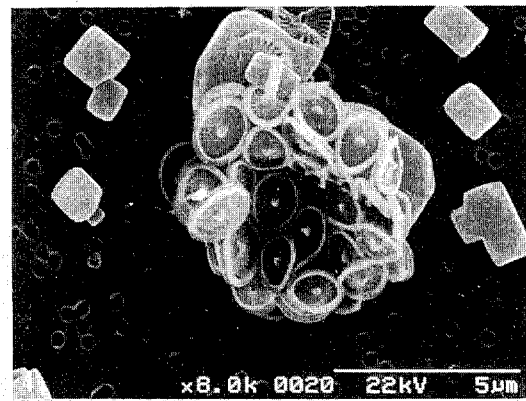
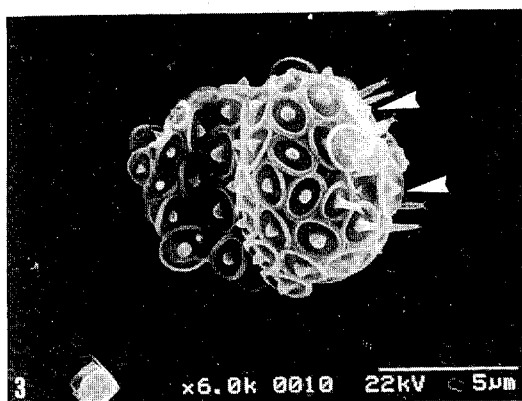
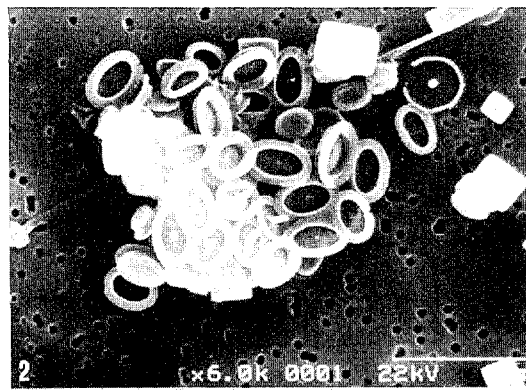
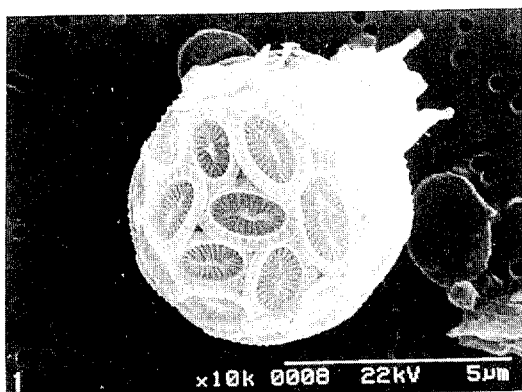
**Figure 4.** Geographic variations of (a) Shannon's index and (b) evenness index of coccoliths and coccospheres. The coccolithophorid communities along the Kuroshio path and in its slope waters are more diversified than that in the continental shelf water and WNPC water.**Figure 5.** Geographic distribution of abundance of coccoliths (a), and standing crops of coccospheres (b). The Kuroshio path shows the highest abundance of coccoliths and coccospheres.

Plate III. Pictures exhibited are all heterococcolithophorid species. 1, *Calciosolenia murrayi* Gran. Detailed view of rhombolith-type coccoliths (scapholiths). (St. 6); 2, *Ceratolithus cristatus* Kamptner. *Neosphaera coccolithomorpha*, heterococcolithophorid form of *Ceratolithus cristatus*. Part of disintegrated coccosphere planoliths. This species is regarded as part of a *Neosphaera-Ceratolithus* combination by Cros et al. (2000), who suggested that the *C. cristatus* has the priority. (St. 17); 3, *Discosphaera tubifera* (Murray et Blackman) Ostenfeld. Disintegrated spherical coccosphere consisting of salpingiform rhabdoliths. (St. 12); 4, *Emiliania huxleyi* (Lohmann) Hay et Mohler. Two coccospheres with distal shield elements and some detached placoliths. (St. 6); 5, *Gephyrocapsa oceanica* Kamptner. Coccosphere showing distinctive transversal bridges. (St. 6); 6, *Ophiaster hydroideus* (Lohmann) Lohmann emend. Manton et Oates. Collapsed coccosphere consisting of elliptical body coccoliths and relatively long and narrow link coccoliths forming arm-like appendages (a) at the posterior pole, and circum-flagellar coccoliths with a spine of the anterior pole. (St. 17); 7, *O. hydroideus* (Lohmann) Lohmann emend. Manton et Oates. Magnified view of Figure 6 showing the detailed body coccoliths and circum-flagellar coccoliths with a spine of the anterior pole. (St. 17); 8, *Palusphaera vandellii* Lecal emend. R.E. Norris. Disintegrated coccosphere consisting of rhabdoliths with a long, very thin styliform process. (St. 30).



(1949) and Hill (1973), respectively. These indices gave consistent results, showing that the Kuroshio community had higher values than either the shelf area or the WNPC water. Stations 12 and 17, downstream from the Kuroshio, had the highest diversity by high values on the evenness and Shannon's index and low values on Simpson's index. On the other hand, the lowest evenness and information content (indicated as *H*) were seen at WNPC water station 24.

The abundance and standing crops of coccoliths and coccospheres, respectively, were estimated and are shown with a compilation of other works in Table 3, and they are drawn in Figure 5. Again, the Kuroshio community exhibits higher abundance/standing crops of coccoliths and coccospheres than other two areas. The largest abundance or standing crops of coccoliths and coccospheres occurred at St. 34 and St. 12, respectively. The standing crops of coccolithophorids are four orders in magnitude

Table 3. Comparison of dominant species, standing crops of coccolithophorids and sampling time recorded here and by other workers.

Location	Dominant species ^a	Standing crop (cells l ⁻¹) ^b	Sampling time	Sources
26.5°N, 124.7°E (St. 12)	<i>E. huxleyi</i> , <i>S. dilatata</i> , <i>U. tenuis</i>	19700 (228000)	20 Jul. 1996, 04:24	This study
26°N, 129.7°E	<i>E. huxleyi</i> , <i>G. ericsonii</i> , <i>G. oceanica</i>	17000	10 Feb. 1978, 07:00	Nishida (1979)
25.8°N, 122.7°E (St. 6)	<i>C.</i> ¹ <i>rigidus</i> , <i>C.</i> ³ <i>divergens</i> , <i>E. huxleyi</i> , <i>S. orbiculus</i>	15300 (102000)	21 Jul. 1996, 05:00	This study
25.5°N, 125°E (St. 17)	<i>C.</i> ² <i>blokkii</i> , <i>G. oceanica</i> , <i>P. vandellii</i> , <i>U. irregularis</i> , <i>U. tenuis</i>	14400 (203000)	19 Jul. 1996, 06:27	This study
24°-26°N, 129°E	Not clear	70-150	16-27 Nov. 1968	Okada & Honjo (1970)
24°-26°N, 142°E	Not clear	600-10000	13 Dec. 1968 to 13 Jan. 1969	Okada & Honjo (1970)
24°-26°N, 150°E	<i>E. huxleyi</i> , <i>U. irregularis</i>	1800-2000	Aug. to Nov. 1969	Okada & Honjo (1973)
24°-26°N, 122°-125°E	Not clear	<10	Oct. to Nov. 1968	Okada & Honjo (1975)
23.8°N, 122°E (St. 34)	<i>E. huxleyi</i> , <i>U. irregularis</i> , <i>U. tenuis</i>	19000 (229000)	16 Jul. 1996, 05:15	This study
23.8°N, 123°E (St. 30)	<i>P. vandellii</i> , <i>S. halldalii</i> , <i>S. nodosa</i> , <i>U. tenuis</i>	11500 (170000)	17 Jul. 1996, 05:00	This study
23.8°N, 125°E (St. 24)	<i>C.</i> ² <i>diconstricta</i> , <i>P. vandellii</i> , <i>S. halldalii</i>	15200 (220000)	18 Jul. 1996, 04:22	This study
23.5°N, 136.5°E	<i>D. tubifera</i> , <i>E. huxleyi</i> , <i>G. oceanica</i> , <i>U. irregularis</i> , <i>U. tenuis</i>	1800	1 Feb. 1978, 08:00	Nishida (1979)
22.7°N, 158°W	<i>E. huxleyi</i> , <i>U. irregularis</i>	<30000	Jan. 1994 to Aug. 1996	Cortés et al. (2001)

^a*C.*¹: *Calciopappus*; *C.*²: *Calicasphaera*; *C.*³: *Calyptrolithina*; *D.*: *Discosphaera*; *E.*: *Emiliana*; *G.*: *Gephyrocapsa*; *P.*: *Palusphaera*; *S.*: *Syracosphaera*; *U.*: *Umbellosphaera*.

^bNumbers show the estimated cell densities per liter of coccospheres, whereas those in parentheses indicate the total abundance of coccoliths in this study.

←

Plate IV. Pictures exhibited are all heterococcolithophorid species. 1, *Syracosphaera exigua* Okada et McIntyre. Dithcate coccosphere with monomorphic endotheca. Caneoliths have a horizontal, ridged distal flange and a central area with an elongate narrow central mound. Some detaching theca present at the upper right corner. (St. 17); 2, *S. halldalii* Jordan et Green. Disintegrated monotheate, dimorphic coccosphere. Body caneoliths with a flat distal flange and circum-flagellar caneoliths with a protrusion in the central area are seen. (St. 17); 3, *S. pirus* Halldal et Markali. Coccosphere dithcate with dimorphic endotheca. Shown are some circular cyrtoliths (arrows) with a narrow outer cycle and a central area of radial laths cover the flagellar area and body caneoliths with a small nodular protrusion and circum-flagellar caneoliths with a long protrusion. (St. 30); 4, *S. prolongata* Gran ex Lohmann. Dithcate coccosphere, cyrtolith not shown, with dimorphic endotheca. Shown here are body caneoliths with a small nodular protrusion in the central area, and a circum-flagellar caneolith with a long protrusion. (St. 17); 5, *S. pulchra* Lohmann. Coccosphere dithcate with dimorphic endotheca. Shown are caneoliths with distal and mid-wall flanges (arrows), and circum-flagellar caneoliths with a long protrusion in the central area. Exotheca cyrtoliths elliptical, convex with a depression in the central area. (St. 30); 6, *Umbellosphaera irregularis* Paasche. Disintegrated coccosphere consisting of high funnel-shaped coccoliths (umbelloliths). (St. 34); 7, *U. tenuis* (Kamptner) Paasche. Disintegrated coccosphere consisting of two sizes of umbelloliths with normal-elliptical central area and distal shield with radial ribs and diagonal ridges with papillae in between. (St. 34); 8, *Umbilicosphaera hultbertiana* Gaarder. Coccosphere with protruding elliptical placoliths. Central elliptical opening in crater-shaped depression is surrounded by a row of nodules on elements of the central tube. (St. 17).



higher than that found by Okada and Honjo (1975) for the marginal seas along the western Pacific, and are more abundant by one to two times those documented by Okada and Honjo (1970; 1973) and Nishida (1979) for the open ocean. Recently, Cortés et al. (2001) also documented higher cell densities than those reported in the Pacific from Jan. 1994 through Aug. 1996 (Table 3), with two episodic increasing standing crops, 40000 and 38000 cells l^{-1} in Mar. 1995 and Aug. 1996, respectively.

Coccolithophorid Communities and Their Floral Characteristics

Calciosolenia murrayi Gran, *Emiliania huxleyi* (Lohmann) Hay et Mohler, *Gephyrocapsa oceanica* Kamptner, *Palusphaera vandellii* Lecal emend. R. E. Norris, *Umbellosphaera irregularis* Paasche, *U. tenuis* (Kamptner) Paasche, and species of *Syracosphaera* Lohmann, dominated the coccolith assemblage in the studied area, while species of *Calicasphaera* Kleijne, *P. vandellii*, *U. irregularis*, *U. tenuis*, and *Syracosphaera* spp., predominated in the coccosphere population (for quantitative details, see Appendix A). Relative abundances of these main taxa are plotted in Figures 6-9. From continental shelf seaward through the Kuroshio path to the WNPC area, we see an increasing trend in the dominance of *P. vandellii*. It also appears that *Syracosphaera* spp. show a similar increasing trend. In contrast, the abundance of *E. huxleyi* decreases along the track.

The continental shelf water (St. 6) is characterized by the dominance of *E. huxleyi*, *G. oceanica* and *C. murrayi* (Figure 6). The Kuroshio path is characterized by *U. irregularis* and *U. tenuis* (Figure 7), but contains also moderately abundant *G. oceanica* (Figure 6). The WNPC water (St. 24) is characterized by a high content of *Calicasphaera* coccospheres. *Palusphaera vandellii*, mostly in coccolith form, is most abundant in the WNPC water and less abundant along the path of the Kuroshio (Figure 8). *Syracosphaera* spp. was distributed ubiquitously in the studied area (Figure 9).

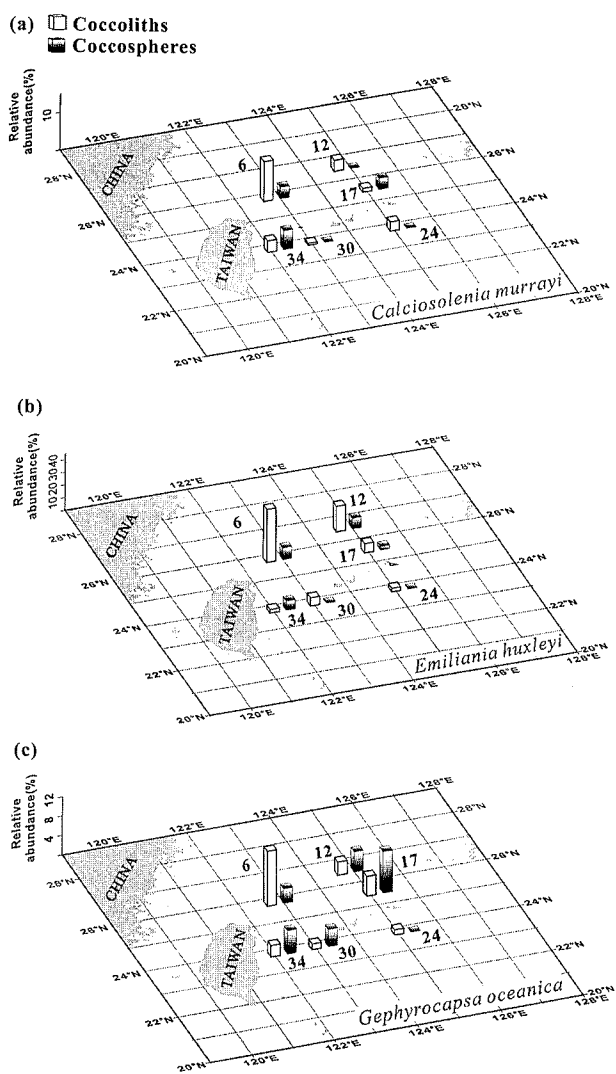


Figure 6. Geographic pattern of the relative abundances of *Calciosolenia murrayi* (a), *Emiliania huxleyi* (b) and *Gephyrocapsa oceanica* (c) in the studied area. These species distributed mainly on the continental shelf of the East China Sea.

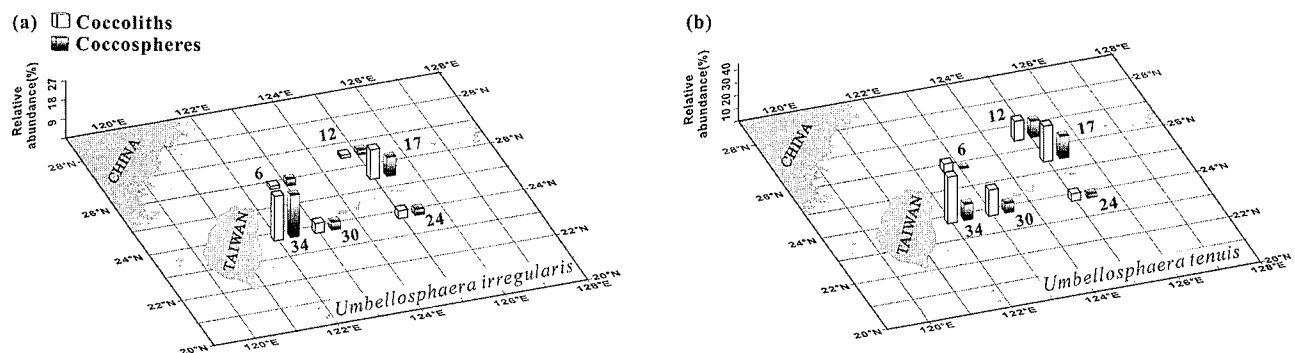


Figure 7. Geographic distribution of *Umbellosphaera irregularis* (a) and *Umbellosphaera tenuis* (b) in the studied area. These species dominated in the Kuroshio and its slope waters.

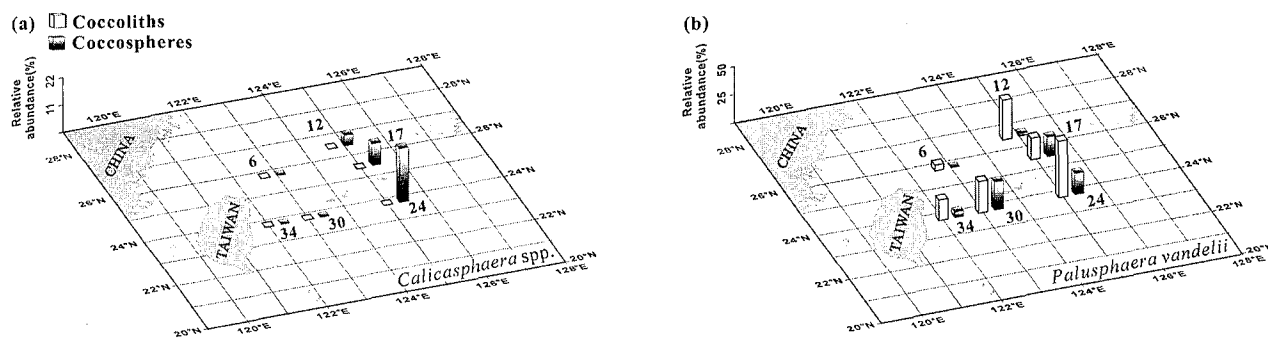


Figure 8. Geographic distribution of dominant species characteristic of the WNPC water: *Calicasphaera* spp. (a) and *Palusphaera vandellii* (b). *Calicasphaera* spp., appeared only as coccospheres, occurred most abundantly in the WNPC water.

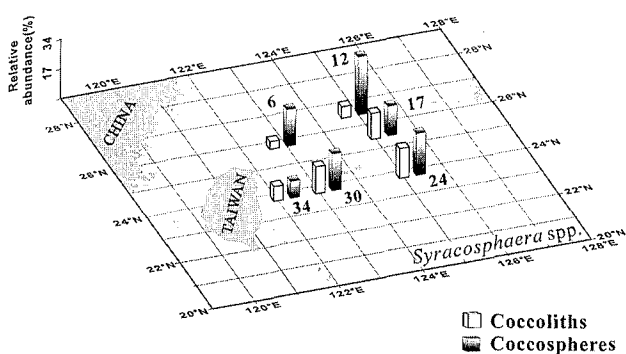


Figure 9. Geographic distribution of the ubiquitous *Syracosphaera* spp.

Discussion

The coccolithophorid distribution in the investigated area can be subdivided into three communities based upon characteristic species: the East China Sea continental shelf community, the Kuroshio current community and the Western North Pacific Water community. Sea surface temperature and salinity over the investigated area are generally very similar except that the continental shelf station has slightly lower temperature and salinity. The depth of nitracline, in contrast, shows distinctive variations among the three communities, increasing progressively from the continental shelf through the Kuroshio towards the open ocean. It is conceivable that the nitracline pattern is responsible for the distribution of the studied coccolithophorids.

It has been documented that the nitrate demand of *E. huxleyi* and *G. oceanica* ($<0.1 \mu\text{mol kg}^{-1}$) is much higher than that of *U. irregularis* (Cortés et al., 2001). The former two species are considered to be opportunistic species thriving in upwelling areas and continental shelf settings, where nutrient concentration in surface water is generally high (Mitchell-Innes and Winter, 1987; Kleijne et al., 1989). On the other hand, *Umbellosphaerids* (e.g., *U. irregularis* and *U. tenuis*) are the most characteristic species of the upper photic zone of oligotrophic waters in the Atlantic and Pacific (McIntyre and Bé, 1967; Okada and McIntyre,

1977; Reid, 1980; Cortés et al., 2001; Haidar and Thierstein, 2001) and in the Mediterranean and Red Sea (Kleijne, 1993; Knappertsbusch, 1990). The dominant forms in the WNPC waters, *P. vandellii* and *Calicasphaera*, were also reported to be major components of tropical and subtropical open-ocean communities (Kleijne, 1992). The distribution pattern in the studied area suggests that they prefer stratified oligotrophic waters.

Conclusions

The distribution of coccolithophorids near the ocean's surface off northeast Taiwan during summer 1996 was quantitatively documented in terms of diversity, abundance/standing crops and community structure. A total of 41 species were identified and tallied with *Emiliania huxleyi*, *Palusphaera vandellii*, *Umbellosphaera* spp. and *Syracosphaera* spp. being the dominant species.

The flow path of the Kuroshio main stream contains more diversified coccolithophorids (20–24 species) than the shelf-waters with the lowest species richness (15 species). The standing crops observed at these stations during summer 1996 are of one to four orders of magnitude higher than those of several previous studies in the Pacific Ocean. The absolute abundances of coccoliths range from 10.2 to 22.9×10^4 per liter, while those of coccospheres range from 11.5 to 19.7×10^3 cells per liter. Generally speaking, the Kuroshio has a higher abundance of coccolithophorids than the continental shelf. Each water-mass has its own dominant characteristic species: *E. huxleyi*, *C. murrayi* and *G. oceanica* for the shelf-water, *Umbellosphaera* spp. for the Kuroshio, and *Palusphaera vandellii* and *Calicasphaera* spp. for the Western North Pacific Central water. The species compositions in each water-mass are affected by the nutrient distributions.

Acknowledgements. The authors would like to thank the officers and crew of the R/V *Ocean Research I*, Mr. Y.-H. Wen and Prof. Y.J. Yang of the Dept. of Applied Science, Chinese Naval Academy for cruise assistance, nutrients analysis and coccolithophorid data processing, respectively. We are greatly appreciative to Prof. C.Y. Huang of Dept. of Geosciences, National Taiwan University for providing the SEM facility. We

are grateful to two anonymous reviewers for their constructive comments and suggestions on the manuscript. This study was supported by Grant NSC-84-2611-M-002-005-K2 (to KYW) and NSC-85-2611-M-019-018-K2 (to GCG) from the National Science Council of the Republic of China.

Literature Cited

- Alcober, J. and R.W. Jordan. 1997. An interesting association between *Neosphaera coccolithomorpha* and *Ceratolithus cristatus* (Haptophyta). *Eur. J. Phycol.* **32**: 91-93.
- Balch, W.M., P.M. Holligan, S.G. Ackleson, and K.J. Voss. 1991. Biological and optical properties of mesoscale coccolithophore blooms in the Gulf of Maine. *Limnol. Oceanogr.* **36**: 629-643.
- Berger, W. 1976. Biogenous deep-sea sediments: production, preservation and interpretation. In J.P. Riley, R. Chester (eds.), *Treatise on Chemical Oceanography*. Academic Press, London, pp. 265-388.
- Brand, L.E. 1994. Physical ecology of marine phytoplankton. In A. Winter and W.G. Siesser (eds.), *Coccolithophores*, Cambridge University Press, pp. 39-49.
- Chao, S.-Y. 1991. Circulation of the East China Sea, a numerical study. *J. Oceanogr. Soc. Japan* **46**: 273-295.
- Chung, W.-S., H.-W. Li, T.Y. Tang, and C.-K. Wu. 1993. Observations of the countercurrent on the inshore side of the Kuroshio northeast of Taiwan. *J. Oceanogr.* **49**: 581-592.
- Cortés, M.Y., J. Bollmann, and H.R. Thierstein. 2001. Coccolithophore ecology at the HOT station ALOHA, Hawaii. *Deep-Sea Res. II* **48**: 1957-1981.
- Cros, L., A. Kleijne, A. Zeltner, C. Billard, and J.R. Young. 2000. New examples of holococcolith-heterococcolith combination coccospheres and their implications for coccolithophorid biology. *Mar. Micropaleont.* **39**: 1-34.
- Figuerola, F.L., F.X. Niell, F.G. Figueriras, and M.L. Villarino. 1998. Diel migration of phytoplankton and spectral light field in the Ria de Vigo (NW Spain). *Mari. Biol.* **130**: 491-499.
- Gong, G.-C. 1992. Chemical Hydrography of the Kuroshio Front in the Sea Northeast of Taiwan. Ph. D. Thesis, Institute of Oceanography, National Taiwan University, 240 pp.
- Gong, G.-C., F.-K. Shiah, K.-K. Liu, W.-S. Chung, and J. Chang. 1997. Effect of the Kuroshio intrusion on the chlorophyll distribution in the southern East China Sea during Spring, 1993. *Conti. Shelf Res.* **17**: 79-94.
- Gong, G.-C., F.-K. Shiah, K.-K. Liu, Y.-H. Wen, and M.-H. Liang. 2000. Spatial and temporal variation of chlorophyll a, primary productivity and chemical hydrography in the southern East China Sea. *Conti. Shelf Res.* **20**: 411-436.
- Graham, W.M., S. MacIntyre, and A.L. Alldredge. 2000. Diel variations of marine snow concentration in surface waters and implications for particle flux in the sea. *Deep-Sea Res. I* **47**: 367-395.
- Groom, S.B. and P.M. Holligan. 1987. Remote sensing of coccolithophore blooms. *Adv. Space Res.* **7**: 73-78.
- Hagino, K., H. Okada, and H. Matsuoka. 2000. Spatial dynamics of coccolithophore assemblages in the Equatorial Western-Central Pacific Ocean. *Mar. Micropaleo.* **39**: 53-72.
- Haidar, A.T. and H.R. Thierstein. 2001. Coccolithophore dynamics off Bermuda (N. Atlantic). *Deep-Sea Res. II* **48**: 1925-1956.
- Hill, M.O. 1973. Diversity and evenness: A unifying notation and its consequences. *Ecology* **54**: 427-432.
- Holligan, P.M., M. Viollier, D.S. Harbour, P. Camus, and M. Champagne-Philippe. 1983. Satellite and ship studies of coccolithophore production along a continental shelf edge. *Nature* **304**: 339-342.
- Honjo, S. 1996. Fluxes of particles to the interior of the open oceans. In V. Ittekkot, P. Schafer, S. Honjo, P.J. Depetris (eds.), *Particles Flux in the Ocean*, SCOPE 57. Wiley, New York, pp. 91-154.
- Hsueh, Y., C.-S. Chern, and J. Wang. 1992. The intrusion of the Kuroshio across the continental slope northeast of Taiwan. *J. Geophys. Res.* **97**: 14323-14330.
- Jordan, R.W. and J.C. Green. 1994. A check-list of the extant Haptophyta of the world. *J. Mar. Biol. Asso. UK* **74**: 149-174.
- Kamptner, E. 1941. Die Coccolithineen der Südwestküste von Istrien, Naturhistorischen Museum in Wien. *Annalen* **51**: 54-149.
- Kleijne, A. 1992. Extant Rhabdosphaeraceae (coccolithophorids, class Prymnesiophyceae) from the Indian Ocean, Red Sea, Mediterranean Sea and North Atlantic Ocean. *Scripta Geol.* **100**: 1-63.
- Kleijne, A. 1993. Morphology, Taxonomy and Distribution of Extant Coccolithophorids (Calcareous Nannoplankton), Vrije Universiteit, 320 pp.
- Kleijne, A., D. Kroon, and W. Zevenboom. 1989. Phytoplankton and foraminiferal frequencies in northern Indian Ocean and Red Sea surface waters. *Neth. J. Sea Res.* **24**: 531-539.
- Knappertsbusch, M.W. 1990. Geographic Distribution of Modern Coccolithophorids in the Mediterranean Sea and Morphological Evolution of *Calcidiscus leptoporus*. Diss. ETH Zurich, Nr. 9169, 140 pp. + figures and plates.
- Lecal-Schlauder, J. 1961. Anomalies dans la composition des coques de flagelles calcaires. Societe d'Histoire Naturelle de l'Afrique du Nord, Bulletin. **52**: 63-66.
- Lie, H.-J., C.-H. Cho, J.-H. Lee, P. Niiler, and J.-H. Hu. 1998. Separation of the Kuroshio water and its penetration onto the continental shelf west of Kyushu. *J. Geophys. Res.* **103**: 2963-2976.
- Liu, K.-K., T.Y. Tang, G.-C. Gong, L.-Y. Chen, and F.-K. Shiah. 2000. Cross-shelf and along-shelf nutrient fluxes derived from fields and chemical hydrography observed in the southern East China Sea off northern Taiwan. *Conti. Shelf Res.* **20**: 493-523.
- McIntyre, A. and A.W.H. Bé. 1967. Modern coccolithophores of the Atlantic Ocean-I. Placolith and cyrtoliths. *Deep-Sea Res.* **14**: 561-597.
- Mitchell-Innes, B.A. and A. Winter. 1987. Coccolithophores; a major phytoplankton component in mature upwelled waters off the Cape Peninsula, South Africa in March, 1983. *Mar. Biol.* **95**: 25-30.
- Nishida, S. 1979. Atlas of Pacific Nannoplanktons, Micropaleontol. Soc. Osaka, Special Paper, No. 3, 31 pp., 23 pls.
- Nitani, H. 1972. Beginning of the Kuroshio. In H. Stommel and K. Yoshida (eds.), *Kuroshio, Physical Aspects of the Japan Current*, University of Washington Press, Seattle, pp. 129-163.

- Okada, H. and A. McIntyre. 1977. Modern coccolithophores of the Pacific and North Atlantic Oceans. *Micropaleont.* **23**: 1-55.
- Okada, H. and S. Honjo. 1970. Coccolithophoridae distributed in Southwest Pacific. *Pacific Geol.* **2**: 11-21.
- Okada, H. and S. Honjo. 1973. The distribution of oceanic coccolithophorids in the Pacific. *Deep-Sea Res.* **20**: 355-374.
- Okada, H. and S. Honjo. 1975. Distribution of coccolithophores in marginal seas along the western Pacific Ocean and in the Red Sea. *Mar. Biol.* **31**: 271-285.
- Qiu, B. and N. Imasato. 1990. A numerical study on the formation of the Kuroshio Counter Current and the Kuroshio Branch Current in the East China Sea. *Conti. Shelf Res.* **10**: 165-184.
- Reid, F.M.H. 1980. Coccolithophorids of the North Pacific Central Gyre with notes on their vertical and seasonal distribution. *Micropaleont.* **26**: 151-176.
- Shannon, C.E. and W. Weaver. 1949. *The Mathematical Theory of Communication*. Urbana, Ill.: Univ. Illinois Press, 117 pp.
- Simpson, E.H. 1949. Measurement of diversity. *Nature* **163**: 688.
- Sun, X.-P. 1987. Analysis of the surface path of the Kuroshio in the East China Sea (In Chinese with English abstract). In X.-P. Sun (ed.), *Essays on the Investigation of the Kuroshio*. China Ocean Press, Beijing, pp. 1-14.
- Sverdrup, H.U., M.W. Johnson, and R.H. Fleming. 1942. *The Oceans: Their Physics, Chemistry and General Biology*. New York, Prentice-Hall, 1060 pp.
- Tang, T.Y. and Y.J. Yang 1993. Low frequency current variability on the shelf break northeast of Taiwan. *J. Oceanog.* **49**: 193-210.
- Tang, T.Y., J.H. Tai, and Y.J. Yang. 2000. The flow pattern north of Taiwan and the migration of the Kuroshio. *Conti. Shelf Res.* **20**: 349-371.
- Tseng, C., C. Lin, S. Chen, and C. Shyu. 2000. Temporal and spatial variations of sea surface temperature in the East China Sea. *Conti. Shelf Res.* **20**: 373-387.
- Westbroek, P., C.W. Brown, J. van Bleijswijk, C. Brownlee, G. J. Brummer, M. Conte, J. Egge, E. Fernández, R. Jordan, M. Knappertsbusch, J. Stefels, M. Veldhuis, P. van der Wal, and J. Young. 1993. A model system approach to biological climate forcing. The example of *Emiliana huxleyi*. *Global Planet. Change* **8**: 27-46.
- Winter, A., R.W. Jordan, and P.H. Roth. 1994. Biogeography of living coccolithophores in ocean waters. In A. Winter and W.G. Siesser (eds.), *Coccolithophores*, Cambridge University Press, pp. 161-177.
- Young, J.R., R.W. Jordan, and L. Cros. 1998. Notes on nanoplankton systematics and life-cycles. *Ceratolithus cristatus*, *Neosphaera coccolithomorpha* and *Umbilicosphaera sibogae*. *J. Nanoplank. Res.* **20**: 89-99.



台灣東北外海表水層鈣板藻及鈣板分佈

楊天南^{1, 2} 魏國彥^{1, 2} 龔國慶³

¹ 國立台灣大學全球變遷研究中心

² 國立台灣大學地質科學系

³ 國立台灣海洋大學海洋科學系

本研究量化報導黑潮與東海陸棚水團交匯所在之台灣東北外海的表水層鈣板藻和鈣板分佈。為減低鈣板藻數量因浮游植物日夜遷移所造成的變動影響，本研究只分析在日出時刻所採取的樣品，對於 1996 年夏天在六個站位採得水深 2 公尺的表層水樣，進行鈣板藻鑑定與計數。共計鑑定出 41 藻種，其中以 *Emiliana huxleyi* (Lohmann) Hay et Mohler、*Palusphaera vandellii* Lecal emend. R. E. Norris、*Umbellosphaera* Paasche 和 *Syracosphaera* Lohmann 為優勢種類。本研究區辨認出三個鈣板藻群落：（一）陸棚群落，優勢種為 *Emiliana huxleyi*、*Gephyrocapsa oceanica* Kamptner 和 *Calciosolenia murrayi* Gran，擁有中度的生物歧異度和種均度；（二）黑潮群落，以 *Umbellosphaera* 屬最為優勢，並表現出最高的種歧異度和種均度；（三）西北太平洋中心區群落，種歧異度和種均度最低，優勢種屬為 *Calicasphaera* Kleijne 及 *Palusphaera vandellii*。每升海水中鬆脫的鈣板數量介於 10.2×10^4 至 22.9×10^4 片，而鈣板球數則介於 11.5×10^3 個至 19.7×10^3 個細胞；其中以黑潮流徑的鈣板和鈣板球含量最高。

關鍵詞：鈣板藻；歧異度；東海；黑潮；生物存量。

