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Seasonal Characteristics of Phytoplankton Dynamics and Environmental Factors in the Coast of Mara-do and U-do, Jeju Island, Korea

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A study on seasonal characteristics of phytoplankton dynamics and environmental factors was carried out at four stations including Mara-do and U-do located in the western and eastern coast of Jeju Island in southern Korea from April 2003 to March 2004. Out of 101 phytoplankton species identified, 84 belong to Bacillariophyceae, 9 Dinophyceae, 6 phytoflagellates and 2 coccolithophorids, and the highest value of species diversity was observed in April. Phytoplankton was more abundant at the western coast than at the eastern coast from March to September and its highest abundance was 49.24×10^3 cells L^{-1} at Mara-do in July. The pennate diatoms were more abundant at the western coast than at the eastern coast with the highest abundance of 38.75×10^3 cells L^{-1} at Mara-do in July, and during this period *Nitzschia longissima* contributed 68.5% of the total phytoplankton abundance. Naviculaceae was more abundant at Gosan (western coast) in November when *Stauroneis membranacea* represented 80.1% of the abundance. *Leptocylindrus danicus* contributed 49.4% of the abundance at U-do in November. Dinophyceae was more abundant at U-do in August. Water temperature and pH fluctuated from 11.7°C to 27.1°C and from 7.31 to 8.70, respectively. Water temperature of Mara-do was about 1-2°C higher than the other stations. Salinity varied from 30.4 to 35.0 psu with the minimum in rainy season and the maximum at the end of winter. The concentration of NH_4-N, NO_3-N, NO_2-N, PO_4-P and SiO_2-Si ranged 0.07-6.79, 1.0-62.0, 1.0-8.0, 1.0-7.0 and 7.0-191.0 μg-at L^{-1}, respectively. Chlorophyll *a* concentrations varied from 0.10 to 1.17 μg L^{-1}. NH_4-N concentrations were high at U-do from May to December, and at Mara-do from January to February. The high concentrations of NO_3-N were found at Mara-do from June to September and at U-do from January to May. The effects of various physicochemical parameters on the seasonal distribution and succession of phytoplankton population suggest that there is a classical pattern of phytoplankton dynamics in Jeju coastal waters.

Key Words: environmental factor, Jeju, phytoplankton, seasonal dynamics

INTRODUCTION

Temporal variability in the structure and function of a phytoplankton community is of fundamental importance to aquatic system. Aquatic environments are subject to high temporal variability, with frequent reorganization of relative abundance and species composition of phytoplankton, as a result of interaction between physical, chemical and biological variables. Water temperature is an important factor controlling the algal growth in natural environments and growth response to water temperature may be essential in regulating the predominance of phytoplankton species (Harris 1986). There is growing evidence that human activities are changing the distribution and movement of nutrient elements resulting in increased nutrients loading to aquatic environments, and the changes of nutrients can alter the species composition of primary producers.

Jeju Island is located at the southern part of South Korea where the East China Sea extends to about 33°20′ N and affected by the Tsushima Warm Current throughout the year. However, the strength of influence by this current would be changed seasonally by the run-off the Changjiang River (Pang *et al.* 1996; Hyun *et al.* 1997) that might be one of the most effective environmental factors for phytoplankton dynamics. The East China Sea receives freshwater as outflow at a rate of 979 km^3 $year^{-1}$ from the Changjiang River, one of the larger river of the world (Beardsley *et al.* 1985; Milliman and Jin 1985). Especially, during the summer the Changjiang River overflows result in the damage of fisheries such as gastropods and fish farms due to low salinity phenomena around the western and southern

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*Corresponding author (jblee@cheju.ac.kr) coast of Jeju Island (Suh *et al.* 1998; Lee *et al.* 1999). Thus these environmental changes should be monitored year to year for protection of fisheries losses. This study was carried out to monitor the changes of phytoplankton dynamics affected by the environmental factors and to compare between the western and eastern coast of Jeju Island, which might be under the control of different environmental influence.

In this study, we analyzed the relationships between phytoplankton population dynamics and hydrodynamic parameters such as temperature, salinity, pH, nutrients, and also compared phytoplankton seasonal dynamics between the western and eastern coast of Jeju Island.

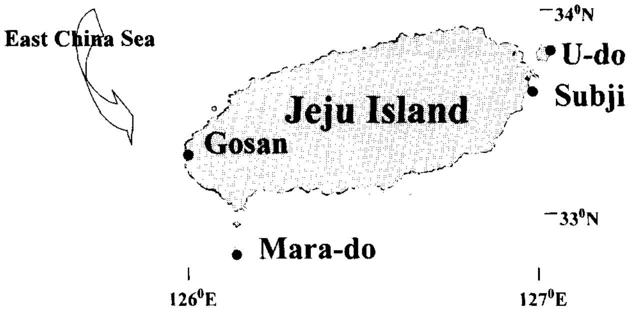

Fig. 1. Map showing sampling stations in the western and eastern coast of Jeju Island.

MATERIALS AND METHODS

We selected two stations at Mara-do (west) and U-do (east) coast as comparing sites (Fig. 1), which reflect the western and eastern features influenced by the East China Sea, respectively, and is far from any human activities. The other two stations at Gosan (west) and Subji (east) coast were selected as reference sites (Fig. 1), which are near fishing villages and influenced by human activities.

Water samples for the observation of phytoplankton and for chemical analyses were collected monthly at four stations (Mara-do, Gosan, U-do and Subji) from April 2003 to March 2004 (Fig. 1). Water samples were collected directly in two different plastic bottles; one for chemical analyses of water quality parameters and another for qualitative and quantitative analyses of phytoplankton. Collected samples for the phytoplankton analysis were fixed with Lugol's iodine solution at the concentration of 2% and after 2-3 days the upper layer was removed by siphoning. Cell counts were determined in a Sedgwick-Rafter cell, using a light microscope. Counting results were summarized as cells per liter. For the taxonomic study, samples were observed under the phase-contrast microscope (Zeiss Axioplan) at a magnification of x 400.

Water samples for nutrients analysis were kept at 4°C and stored in a freezer for further laboratory analysis. NO_3-N, NO_2-N, NH_4-N, PO_4-P, SiO_2-Si and chlorophyll *a* were estimated by the spectrophotometer (Shimadzu UV-1201) according to the method of Parsons *et al.* (1984). Water temperature and salinity were measured with thermo-salinity meter (YSI 85) and pH with pH meter (Orion 920A). For statistical analysis SYSTAT v8.0 was used and all correlation coefficients(r) were calculated within $p < 0.05$.

RESULTS

Environmental factors

During the study, water temperature represented a typical seasonal cycle characterized by the minimum of 11.7°C at Subji in January and the maximum of 27.1°C at Mara-do in August. In comparison between Mara-do and U-do, the highest water temperature was found at Mara-do in August and the lowest at U-do in January (Fig. 2). Throughout the year water temperature at Mara-do was found to be higher about 1-2°C than the other stations except in June when U-do showed the highest water temperature.

Salinity ranged from 30.4 to 35.0 psu throughout the year with the minimum at all stations in August and September and the maximum at Subji in February. The measured salinity did not fluctuate significantly from one station to another station during the same sampling period. However salinity at Mara-do was lower than at U-do from June to August and from December to February (Fig. 2). All stations exhibited significantly negative relationships between water temperature and salinity (Mara-do, r = -0.93; U-do, r = -0.92; Gosan, r = -0.95; Subji, r = -0.89).

Higher pH values were observed from late spring to autumn, whereas the lower values were from winter to early spring. Fluctuation of pH was 7.31 to 8.70 with the lowest at Gosan in January and the highest at Subji in October. In comparison between Mara-do and U-do, the pH was found to be higher at U-do throughout the year except winter season (November to February) (Fig. 2).

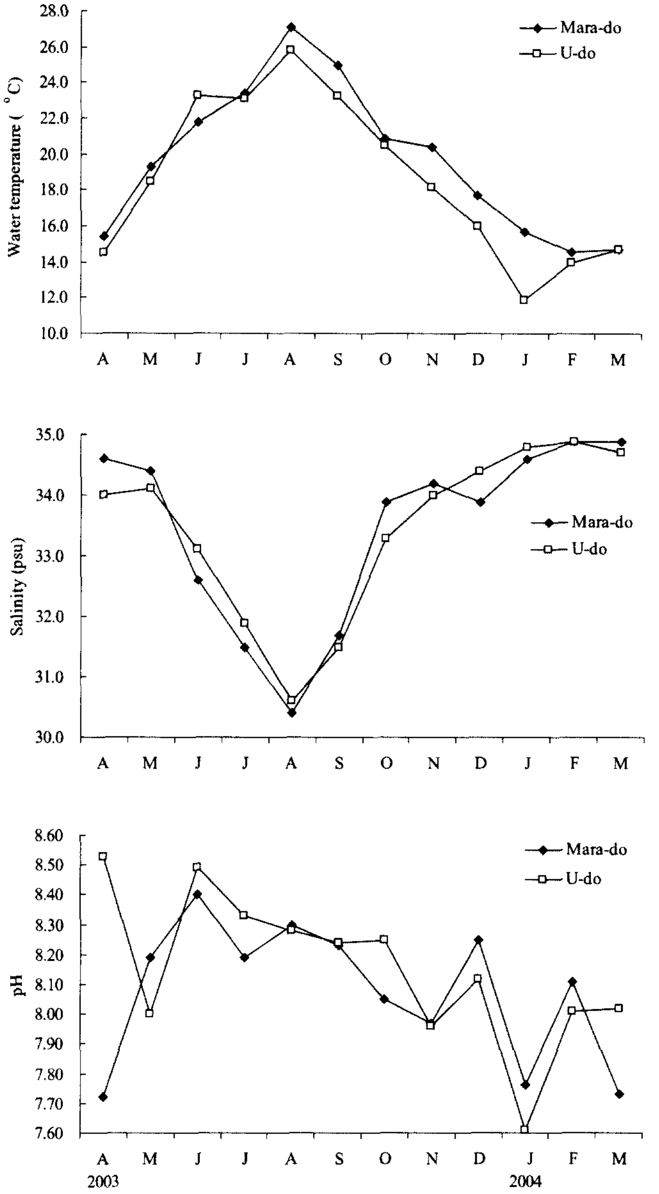

Fig. 2. Monthly variations of water temperature, salinity and pH at Mara-do and U-do coast of Jeju Island from April 2003 to March 2004.

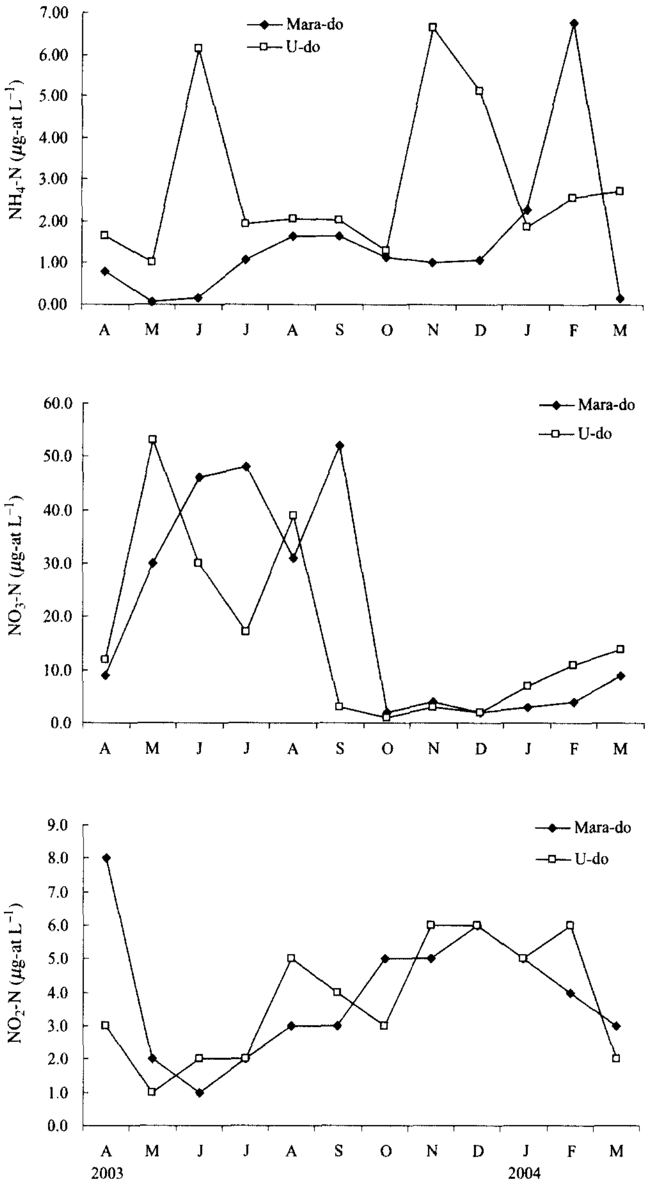

Fig. 3. Monthly variations of NH_4-N, NO_3-N, and NO_2-N at Mara-do and U-do coast of Jeju Island from April 2003 to March 2004.

The positive relationships between pH and water temperature was observed at Mara-do (r = 0.70), Gosan (r = 0.60), U-do (r = 0.60) and Subji (r = 0.70).

The concentrations of NH_4-N varied from 0.07 to 6.79 μg-at L^{-1} at all stations. NH_4-N concentrations at U-do were higher in most months than at Mara-do except January and February (Fig. 3). Ammonia exhibited significantly negative relationships with water temperature (r = -0.69) and with pH (r = -0.70) at Gosan, but it showed positive relationships with salinity (r = 0.50) at Subji.

The NO_3-N concentrations ranged from 1.0 μg-at L^{-1} at U-do in October to 62.0 μg-at L^{-1} at Subji in May. The high concentrations were observed frequently during summer seasons at almost stations. In comparison between Mara-do and U-do, the higher concentrations of NO_3-N were found at Mara-do from June to September, and at U-do from January to May (Fig.3). At Mara-do NO_3-N displayed significantly positive relationships with water temperature (r = 0.72) and with pH (r = 0.57), and negative relationships with salinity (r = -0.73). At Gosan, NO_3-N showed positive relationships with water temperature (r = 0.70) and negative relationships with salinity (r = -0.60).

NO_2-N concentrations, ranging from 1.0 to 8.0 μg-at L^{-1}, showed the lower values at all stations in the months

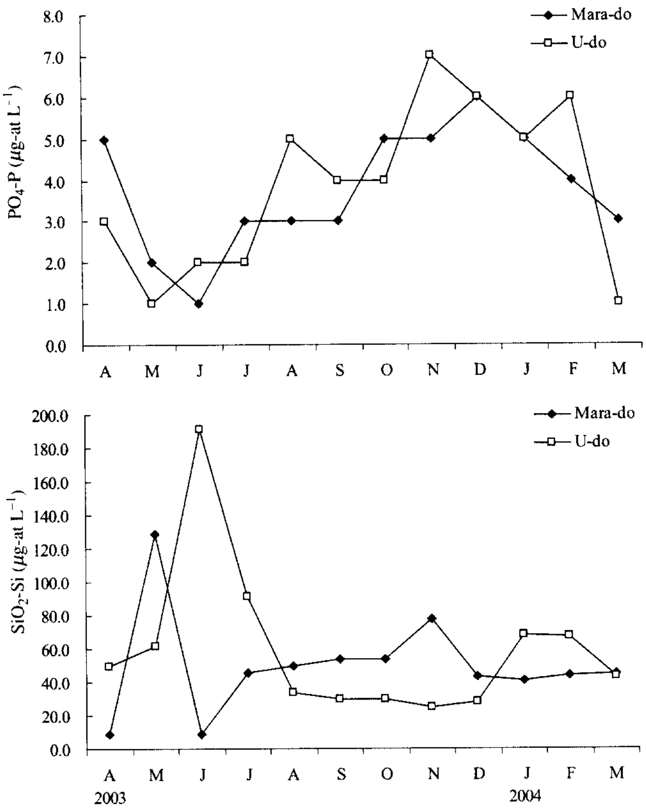

Fig. 4. Monthly variations of PO_4-P and SiO_2-Si at Mara-do and U-do coast of Jeju Island from April 2003 to March 2004.

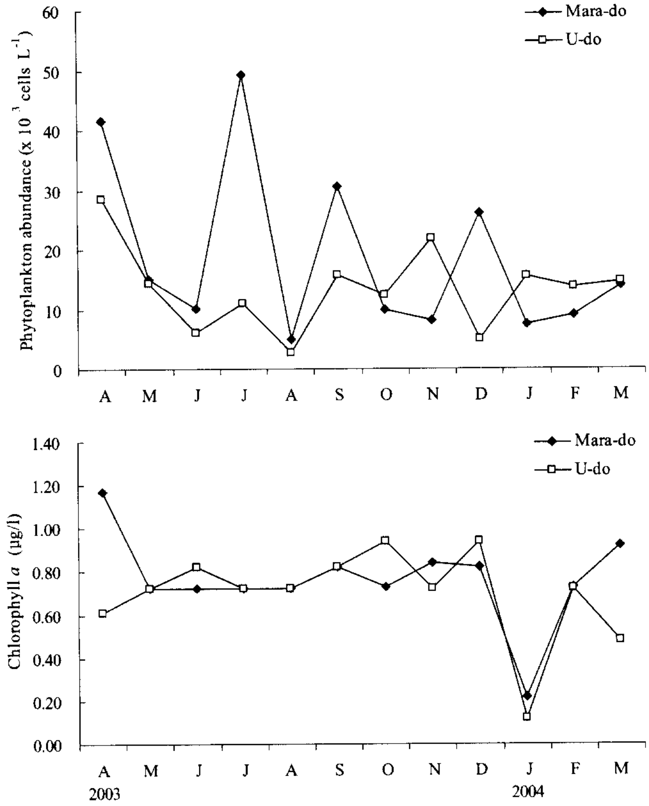

Fig. 5. Monthly variations of phytoplankton abundance and chlorophyll *a* at Mara-do and U-do coast of Jeju Island from April 2003 to March 2004.

of May to July and the highest at Mara-do in April. Higher concentrations of NO_2-N were observed frequently during the winter season with the maximum in December at all stations. NO_2-N concentrations were found to be higher at U-do than at Mara-do from June to February except in October (Fig. 3). NO_2-N showed negative relationships with pH (r = -0.59) at Mara-do.

The phosphate concentrations varied from 1.0 to 7.0 μg-at L^{-1}, which were frequently high in winter (November to January) and followed by spring (February to April), autumn (August to October) and summer (June to July). In Mara-do and U-do, PO_4-P concentrations were high at U-do from August to December and at Mara-do from April to May (Fig. 4). PO_4-P showed negative relationships with pH (r = -0.60) at Mara-do.

The concentrations of SiO_2-Si varied from 7.0 at Subji in April to 191.0 μg-at L^{-1} at U-do in June. At Mara-do, SiO_2-Si concentrations showed higher value than at U-do from August to December and lower ones from January to April (Fig. 4).

Standing crops and biomass of phytoplankton

Phytoplankton abundance, ranging from 2.28×10^3 - 49.24×10^3 cells L^{-1}, showed the lowest in August and the highest in July at Mara-do. In the eastern coast, the highest phytoplankton abundance was 39.38×10^3 cells L^{-1} at Subji and 28.45×10^3 cells L^{-1} at U-do in April. Phytoplankton abundance was higher at Mara-do than at U-do throughout the year except October to November (Fig. 5). The abundance was frequently high during the months of spring (March-April) in all stations, decreasing sequentially in summer (June-July), autumn (September-October), and winter (December-February). Phytoplankton exhibited significantly negative relationship (r = -0.50) with water temperature at U-do and positive relationship (r = 0.56) with chlorophyll *a* at Subji.

Chlorophyll *a* concentrations varied from 0.10 to 1.17 μg L^{-1} throughout the year with the highest at Subji in April and the lowest at Gosan in January. In comparison between Mara-do and U-do, the highest chlorophyll *a* (1.17 μg-at L^{-1}) was at Mara-do in April and lowest (0.12 μg-at L^{-1}) at U-do in January (Fig. 5).

Table 1. Systematic list of phytoplankton identified at four stations in the western and eastern coast of Jeju Island during the study

Division CHRYSOPHYTA
Class Bacillariophyceae
Order Centrales
Family Coscinodiscaceae Kützing 1844

- Genus *Coscinodiscus* Ehrenberg 1838
  - *Coscinodiscus centralis* Ehrenberg
  - *Coscinodiscus jonesianus* Greville
  - *Coscinodiscus marginatus* Ehrenberg
  - *Coscinodiscus radiatus* Ehrenberg
  - *Coscinodiscus rothii* (Ehrenberg) Grunow
  - *Coscinodiscus stellaris* Roper
  - *Coscinodiscus wailesii* Gran et Angst

Family Rhizosoleniaceae

- Genus *Guinardia* H. Peragallo 1892
  - *Guinardia flaccida* (Castracane) H.Peragallo
- Genus *Rhizosolenia* Brightwell 1858
  - *Rhizosolenia delicatula* Cleve
  - *Rhizosolenia fragilissima* Bergon
  - *Rhizosolenia stolterforthii* H. Peragallo

Family Eupodiscaceae Kützing 1849

- Genus *Odontella* Agardh 1832
  - *Odontella mobiliensis* (J.W. Bailey) Grunow

Family Thalassiosiraceae Lebour 1930, emend Hasle 1974

- Genus *Detonula* Schütt 1893
  - *Detonula pumila* (Castracane) Schutt
- Genus *Planktoniella* Schütt 1893
  - *Planktoniella sol* (G.C. Wallich) Schutt
- Genus *Skeletonema* Greville 1865
  - *Skeletonema costatum* (Greville) Cleve
- Genus *Stephanodiscus* Ehrenberg 1845
  - *Stephanodiscus rotula* (Kützing) Hendey
- Genus *Thalassiosira* Cleve 1873
  - *Thalassiosira condensata* Cleve 1900
  - *Thalassiosira hyalina* (Grunow in Cleve et Grunow) Gran
  - *Thalassiosira pacifica* Gran et Angst
  - *Thalassiosira subtilis* (Ostenfeld) Gran

Family Melosiraceae Kützing 1844

- Genus *Hyalodiscus* Ehrenberg 1845
  - *Hyalodiscus scoticus* (Kützing) Grunow
- Genus *Leptocylindrus* Cleve 1889
  - *Leptocylindrus danicus* Cleve
  - *Leptocylindrus minimus* Gran
- Genus *Melosira* Agardh 1824
  - *Melosira moniliformis* (O.F. Muller) Agardh
- Genus *Paralia* (Ehrenberg) Cleve 1873
  - *Paralia sulcata* (Ehrenberg) Cleve
- Genus *Stephanopyxis* Ehrenberg 1845
  - *Stephanopyxis palmeriana* (Greville) Grunow

Family Heliopeltaceae H. L. Smith 1872

- Genus *Actinoptychus* Ehrenberg 1841
  - *Actinoptychus senarius* Ehrenberg

Family Biddulphiaceae Kützing 1844

- Genus *Biddulphia* Gray 1821
  - *Biddulphia longicruris* Greville
  - *Biddulphia pulchella* Gray
- Genus *Eucampia* Ehrenberg 1839
  - *Eucampia zodiacus* Ehrenberg

Family Chaetoceraceae H.L. Smith 1872

- Genus *Bactreiastrum* Shadbolt 1854
  - *Bacteriastrum elegans* Pavillard
- Genus *Chaetoceros* Ehrenberg 1844
  - *Chaetoceros affinis* Lauder
  - *Chaetoceros brevis* Schütt
  - *Chaetoceros constrictus* Gran
  - *Chaetoceros convolutus* Castracane
  - *Chaetoceros costatus* Pavillard
  - *Chaetoceros danicus* Cleve
  - *Chaetoceros didymus* Ehrenberg
  - *Chaetoceros lorenzianus* Grunow
  - *Chaetoceros muelleri* Lemmermann
  - *Chaetoceros pendulus* Karsten
  - *Chaetoceros peruvianus* Brightwell
  - *Chaetoceros pseudocrinitus* Ostenfeld
  - *Chaetoceros simplex* Ostenfeld

Family Lithodesmiaceae H. et M. Peragallo 1897

- Genus *Ditylum* L.W. Bailey 1861
  - *Ditylum brightwellii* (T. West) Grunow in Van Heurck
  - *Ditylum sol* Grunow in Van heurck

Order Pennales
Family Achnanthaceae Kützing 1844

- Genus *Achnanthes* Bory 1822
  - *Achnanthes longipes* Agardh
- Genus *Cocconeis* Ehrenberg 1838
  - *Cocconeis scutellum* Ehrenberg

Family Naviculaceae 1844 Kützing

- Genus *Ampiprora* Kützing 1844
  - *Ampiprora alata* (Ehrenberg) Kützing
- Genus *Amphora* Ehrenberg ex Kützing 1844
  - *Amphora decussata* Grunow
- Genus *Caloneis* Cleve 1894
  - *Caloneis crassa* (Gregory) R. Ross
  - *Caloneis* sp.
- Genus *Navicula* Bory 1822
  - *Navicula distans* (W. Smith) Rafls in Pritchard
  - *Navicula elegans* W. Smith
  - *Navicula oblonga* (Kützing) Kützing
  - *Navicula viridula* (Kützing) Ehrenberg
  - *Navicula vula* J.R. Carter
- Genus *Pleurosigma* W. Smith 1853
  - *Pleurosigma* sp.
- Genus *Stauroneis* Ehrenberg 1843
  - *Stauroneis membranacea* (Cleve) Hustedt
- Genus *Tropidoneis* Cleve 1891
  - *Tropidoneis lepidoptera* (Gregory) Cleve

Family Nitzschiaceae Grunow

- Genus *Bacillaria* Gmelin 1791
  - *Bacillaria paxillifer* (O.F. Müller) Hendey
- Genus *Cylindrotheca* Rabenhorst 1859
  - *Cylindrotheca closterium* (Ehrenberg) Reimann et Lewin
- Genus *Nitzschia* Hassall 1845

Table 1. (continued)

  - *Nitzschia angularis* W. Smith
  - *Nitzschia denticula* Grunow in Cleve et Grunow
  - *Nitzschia frustulum* (Kützing) Grunow
  - *Nitzschia longissima* (Brébisson in Kützing) Ralfs in Pritchard
  - *Nitzschia panduriformis* Gregory
  - *Nitzschia sigma* (Kützing) W. Smith
  - *Nitzschia socialis* Gregory
- Genus *Pseudo-nitzschia* H. et M. Peragallo 1900
  - *Pseudo-nitzschia delicatissima* (Cleve) Heiden et Kolbe
  - *Pseudo-nitzschia pungens* (Grunow ex Cleve) Hasle
  - *Pseudo-nitzschia seriata* (Cleve) H. et M. Peragallo
- **Family Diatomaceae Dumortier 1822**
- Genus *Fragilaria* Lyngbye 1819
  - *Fragilaria capucina* Désmazières
  - *Fragilaria striatula* Lyngbye
- Genus *Grammatophora* Ehrenberg 1840
  - *Grammatophora angulosa* Ehrenberg
  - *Grammatophora marina* (Lyngbye) Kützing
- Genus *Licmophora* Agardh 1827
  - *Licmophora abbreviata* Agardh 1831
  - *Licmophora gracilis* (Ehrenberg) Grunow
  - *Licmophora paradoxa* (Lyngbye) Agardh
- Genus *Meridion* Agardh 1824
  - *Meridion circulare* (Greville) Agardh
- Genus *Tabellaria* Ehrenberg ex Kützing1844
  - *Tabellaria flocculosa* (Roth) Kützing
- Genus *Thalassionema* Grunow ex Hustedt 1932
  - *Thalassionema nitzschioides* Grunow ex Hustedt
  - *Thalassionema frauenfeldii* (Grunow) Hallegraeff
- Genus *Thalassiothrix* Cleve et Grunow 1880
  - *Thalassiothrix longissima* Cleve et Grunow
- **Division PYRROPHYTA**
- **Class Dinophyceae**
- **Order Prorocentrales**
- **Family Prorocentraceae Scüttt 1896**
- Genus *Prorocentrum* Ehrenberg 1833
  - *Prorocentrum balticum* (Lohmann) Loeblich
  - *Prorocentrum compressum* (Bailey) Abé ex Dodge
  - *Prorocentrum triestinum* Schiller
- **Order Dinophysiales**
- **Family Dinophysiaceae Pavillard 1916**
- Genus *Dinophysis* Ehrenberg 1839
  - *Dinophysis rotundata* Claparede et Lachmann
- **Order Gonyaulacales**
- **Family Ceratiaceae Lindenmann 1924**
- Genus *Ceratium* Schrank 1793
  - *Ceratium fusus* (Ehrenberg) Dujardin
  - *Ceratium lineatum* (Ehrenberg) Cleve
- **Order Peridiales**
- **Femily Protoperidiniaceae Balech 1974**
- Genus *Protoperidinium* Bergh 1881
  - *Protoperidinium brochii* (Kofoid et Swezy) Balech
  - *Protoperidinium depressum* (Bailey) Balech
  - *Protoperidinium oceanicum* (Van Höffen) Balech
- **Division CHLOROPHYTA**
- **Class Chlorophyceae**
- **Order Volvocales Oltmanns 1904**
- **Family Chlamydomonadaceae G.M. Smith 1920**
- Genus *Chlamydomonas* Ehrenberg 1834
  - *Chlamydomonas coccoides* Butcher
  - *Chlamydomonas pulsatilla* Wollenweber
- **Division EUGLENOPHYTA**
- **Class Euglenophyceae**
- **Order Euglenales Engler 1898**
- **Family Euglenaceae Dujardin 1841**
- Genus *Euglena* Ehrenberg 1838
  - *Euglena* sp.
- **Family Eutreptiaceae Leedale 1967**
- Genus *Eutreptiella* de Cunha 1914
  - *Eutreptiella gymnastica* Throndsen
  - *Eutreptiella marina* de Cunha
- **Division CHROMOPHYTA**
- **Class Chryptophyceae**
- **Order Cryptomonadales Engler 1903**
- **Family Hilleaceae Butcher 1967**
- Genus *Hillea* Schiller 1925
  - *Hillea fusiformis* Schiller
- **Class Prymnesiophyceae**
- **Order Coccosphaerales Haeckel 1894**
- **Family Coccolithaceae Poche 1913**
- Genus *Calcidiscus* Kamptner 1950
  - *Calcidiscus leptoporus* Loeblich et Tappan
- **Family Calciosoleniaceae Kamptner 1937**
- Genus *Anoplosolenia* Deflandre 1952
  - *Anoplosolenia brasiliensis* (Lohman) Deflandre

Taxonomic composition and succession of phytoplankton

The object of species identification was to obtain an environmental function rather than a strictly taxonomic classification of the organisms. A total of 101 phytoplankton, including 84 Bacillariophyceans, 9 Dinophyceans, 6 phytoflagellates and 2 coccolithophorids, were identified during the study (Table 1).

The highest values of species diversity were observed in April at all stations and the species diversity indices were 3.65, 3.49, 3.22 and 3.11, and the numbers of species were 44, 36, 25 and 30 at Gosan, U-do, Mara-do and Subji, respectively (Table 2).

During the study, a special emphasis was given on the occurrence, abundance and succession of Bacillariophyceae. The Bacillariophyceae abundance varied from 2.03×10^3 to 46.50×10^3 cells L^{-1} with the highest at Mara-do in July and the lowest at the same

Table 2. Species diversity indices at the western and eastern coast of Jeju Island during the study

Months		Mara-do	Gosan	U-do	Subji
2003	APR	3.22	3.65	3.49	3.11
	MAY	3.04	2.89	3.02	2.64
	JUN	2.34	3.59	2.34	3.59
	JUL	1.34	2.93	2.89	2.78
	AUG	2.77	3.00	2.34	3.01
	SEP	2.59	2.54	3.00	2.54
	OCT	2.62	2.38	2.31	2.82
	NOV	2.60	1.07	2.12	2.68
	DEC	2.38	3.00	2.14	3.02
2004	JAN	2.50	2.43	2.40	2.49
	FEB	2.33	2.77	2.68	2.63
	MAR	2.65	2.88	2.85	2.67

station in August. Bacillariophyceae contributed more than 75% in all stations and the highest contribution was 94.5% at Mara-do in July.

Pennate diatoms were found to be more abundant on the western coast than at the eastern coast throughout the study period. The highest abundance (38.75 × 10^3 cells L^{-1}) of pennate diatoms was recorded at Mara-do in July, followed by April, and by September to December. At Gosan, the maximum abundance of pennate diatoms was 29.54 × 10^3 cells L^{-1} in March. At Subji, two peaks of abundance of pennate diatoms was observed; one (16.80 × 10^3 cells L^{-1}) in April and another (16.01 × 10^3 cells L^{-1}) in September. At U-do, the higher pennate diatom abundances were recorded in April with 10.48 × 10^3 cells L^{-1} and in September with 9.80 × 10^3 cells L^{-1}.

The highest abundance of centric diatoms was 16.76 × 10^3 cells L^{-1} at Gosan in autumn, followed by summer, spring and winter. U-do station showed the higher abundances of centric diatoms (16.22 × 10^3 cells L^{-1}) than Mara-do station in April. At Subji two peaks of centric diatom abundances were observed; one in spring months with 12.07 × 10^3 cells L^{-1} in April and another with 13.1 × 10^3 cells L^{-1} in September.

The most frequently occurring species of pennate diatoms in terms of cell density was Nitzschiaceae and followed by Naviculaceae and Diatomaceae. Among *Nitzschia* species, *Nitzschia longissima* as a single species played a major role in the occurrence of the highest Bacillariophyceae abundance at Mara-do in July. The abundance of this species was 33.74 × 10^3 cells L^{-1} which contributed 68.5% of the total phytoplankton abundance and 74.1% of the Bacillariophyceae (Table 3).

Naviculaceae showed their maximum abundance at Gosan in November and during that period *Stauroneis membranacea* contributed 80.1% of phytoplankton abundance (Table 3). At U-do *Navicula oblonga* and *Navicula viridula* contributed 15.6% and 12.5% of total abundance (Table 3).

Among the centric diatoms, Chaetoceraceae, Coscinodiscaceae, Thalassiosiraceae, Achnanthaceae, Melosiraceae was found to be dominant taxa during the study period, but they do not occur so frequent at all stations in all months. *Leptocylindrus danicus,* a species of Melosiraceae occupied 49.40% of phytoplankton at U-do in November (Table 3). The higher occupation of *Chaetoceros* at each station was 63.0%, 30.1%, 28.9% and 28.1% at Subji in June, at Mara-do in April, at Gosan in October, and at U-do in April, respectively. *Chaetoceros costatus, C. pendulus, C. danicus, C. pseudocrinitus* were the common species in the Chaetoceraceae. When *Chaetoceros* predominated at Subji, *C. pseudocrinitus* and *C. pendulus* represented 20.1% and 19.6% of the phytoplankton abundance. At Mara-do *C. danicus* showed its maximum presence (10.4%) in April, but in October *C. pseudocrinitus* contributed 23.3%. At Gosan, *C. pseudocrinitus* contributed 28.9% reaching up to 8.98 × 10^3 cells L^{-1} in October.

Different species of Dinophyceae was found throughout the year but their maximum density was observed at U-do in August, and during the period *Prorocentrum balticum* and *P. triestinum* contributed 16.7% and 13.3% of phytoplankton abundance.

Phytoflagellates were found from spring to summer and *Chlamydomonas* sp. and *Euglena* sp. were common. Two species of Coccolitophorids were observed in July, of which one was *Calcidiscus leptoporus* at U-do and another *Anoplosolenia brasiliensis* at Subji.

DISCUSSION

Dynamics of environmental factors

Both the eastern and western part of Jeju coastal waters exhibited a good relation with environmental variables and phytoplankton assemblage. The environmental variables strongly determine the seasonal variations in the temporal distribution of phytoplankton population. Water temperature, salinity, and nutrients input regimes exhibited a well-defined seasonal pattern.

The occurrence of higher water temperature throughout the year at the western coast in comparison to the eastern coast suggests that this area is highly affected by the Tsushima Current, as this warm current introduces from the East China Sea as a branch of

Table 3. Seasonal dynamics of dominant phytoplankton at the Mara-do and U-do coast of Jeju Island during the study

Species Name	Mara-do												U-do											
	2003									2004			2003									2004		
	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M
Diatoms																								
Amphora decussata											*											*		
Bacillaria paxillifer								*																
Bacteriastrum elegans								*																
Biddulphia pulchella											*													
Chaetoceros constrictus			*																					
Ch. costatus																						*		
Ch. danicus	*																							
Ch. didymus												*												
Ch. pseudocrinitus							**																	
Cocconeis scutellum														*		*					*	*		
Cylindrotheca closterium																						*		
Ditylum brightwellii			*																					
Eucampia zodiacus																							**	
Grammatophora marina								*																
Leptocylindrus danicus																				***				
Licmophora paradoxa					*														*		*			
Navicula oblonga			*												*									
N. viridula					*										*									
N. vula																					*			
Nitzschia angularis																			**					
N. longissima				***											*						*			
Pseudo-nitzschia seriata						**			**	*														
Rhizosolenia stolterforthii									*		*													
Thalassionema nitzschioides											*											*		
Thalassiosira subtilis														*										
Thalassiothrix frauenfeldii															*									
Th. longissima											*													
Dinoflagellates																								
Ceratium lineatum																					*			
Prorocentrum balticum																	*							
P. compressum																							*	
P. triestinum																	*							
Protoperidinium oceanicum						*			*							*								

Remark: * indicates 10 to 19.9%, ** 20 to 39.9% and *** above 40% of total phytoplankton abundance.

Kuroshio Current (Pang *et al.* 1996). The flow of warm and saline waters from the East China Sea to the Korea Strait is a primary flow around Jeju Island (Pang *et al.* 1992).

High salinity of these coastal areas in winter and the negative correlation of salinity with water temperature suggest that these areas are highly affected by strong Tsushima Current, as this current brings high saline and cold subsurface water to the surface by the upwelling (Pang *et al.* 1996). At about 30°N along the continental margin in the East China Sea, the Kuroshio begins to turn eastward and there is a general separation of the flow of the Kuroshio and the separated Kuroshio flow on the left-hand side is known to give rise to the Tsushima Current (Hsueh 2000). In summer (June-July), the occurrence of lower salinity in Mara-do suggests that the western part of Jeju coastal water is diluted by the overflows of the Changjiang River.

The occurrence of high nutrient concentrations, especially NO_3-N concentration in summer, and the strongly positive relationship between NO_3-N and water temperature at Mara-do may reflect the continuous discharge of nutrient rich water through the overflow of the Changjiang River. Our finding is similar with the result of Edmond *et al.* (1985) who reported that the Changjiang River is an unusually combined nitrogen rich river where nitrate concentrations are as high as 70 μM. They also found that the annual net export of nitrate to the East China Sea through the Changjiang River has been estimated to be 60×10^9 mole per year. In this study NO_3-N exhibited negative relationships (r = -0.73) with salinity at Mara-do. Our result is closely similar with the findings of Gu (1990) and Tang *et al.* (1990) who reported that the concentration of nitrate increases while salinity decreases towards the northwest of the sea and especially toward the mouth of the Changjiang River.

The occurrence of higher concentration of NH_4-N at all stations during winter and at U-do in June may be associated with lower standing crops, because in this time the occurrence of phytoplankton abundance was lower. This lower cell density during the higher occurrence of NH_4-N indicates that this nutrient was not taken up by the phytoplankton. Frequent occurrence of higher concentration of NO_2-N and PO_4-P in winter season may be the upwelling of nutrient rich – cold subsurface water in winter season, as the strength of Kuroshio Current is higher. Chen (1996) reported that the nutrients rich and cold subsurface water of Kuroshio Current could reach the shelf through topographically induced upwelling. In winter the entire continental area is occupied by nutrient rich water (Gong *et al.* 1995). There may be another biological factor such as low uptake of nutrients due to the strong mixing, low irradiance level and low water temperature in winter, which might affected the frequent occurrence of higher concentrations of NO_2-N and PO_4-P as well as NH_4-N during the winter. Lee *et al.* (1989, 1990) reported that microalgal abundance around Jeju Island generally decreased due to low water temperature in winter.

Phytoplankton assemblage dynamics with environmental factors

Though the highest abundance of phytoplankton was at Mara-do in July, higher abundance and the highest species diversity were observed at all stations in April. The reason for these phenomena may be the rising water temperature, occurrence of phytoplankton species disappeared during winter, increasing irradiance and availability of upwelling nutrients during the winter.

It is well established that diatom is the most dominant group of phytoplankton in coastal waters, and we also found the same result that diatom was the dominant group among the phytoplankton population at all stations.

In general, the phytoplankton succession pattern at the western part of Jeju Island agrees with nutrient (i.e., NO_3-N) input and salinity dynamics through the overflows of Changjiang River during summer (June-July). Hyun and Pang (1998) reported that massive water of the Changjiang River has frequently reached the southern coast of Jeju Island in summer season. During this period the highest (49.24×10^3 cells L^{-1}) phytoplankton abundance was found at Mara-do on the western coast of Jeju Island and the pennate diatom was the most dominant group. *Nitzschia longissima* species was the most abundant among the Bacillariophyceae, when the environmental situation comprised rising temperature (23.4°C), moderate salinity (31.5 psu) and higher (48.0 μg-at L^{-1}) NO_3-N concentration, which might have created the most favourable conditions for the growth of phytoplankton. This result agrees well with Lee and Kim (2002) who reported that *Nitzschia* sp. grew well in wide range of salinity (20.0 to 40.0 psu) with 13.57 mg L^{-1} of total nitrogen concentration at 20°C during the determination of growth characteristics of micro-algal species isolated from Jeju Island.

Naviculaceae showed their maximum abundance at Gosan in November and during the period *Stauroneis membranacea* contributed 80.2% of phytoplankton abundance. Decreased water temperature (19.1°C), high salinity (34.0 psu), and nutrient concentrations of PO_4-P (6.0 μg-at L^{-1}), NO_3-N (6.0 μg-at L^{-1}) and SiO_2-Si (112.0 μg-at L^{-1}) in winter might have created a most favourable environment for the highest growth of *Stauroneis membranacea.* At U-do the highest (28.1%) occurrence of Naviculaceae was recorded in June, during this period *N. oblonga* and *N. viridula* contributed 15.6% and 12.5% of total phytoplankton, respectively. Though June is summer with rainy season, the salinity of this area is not affected by any river overflows like the western coast of Jeju Island. So the occurrence of highest percent of *N. oblonga* and *N. viridula* may be caused by higher salinity (33.1 psu) and good water temperature (23.3°C) with higher concentration of nitrogenous nutrients and SiO_2-Si (191.0 μg-at L^{-1}).

Among the centric diatoms, Melosiraceae and Chaetoceraceae occurred with their remarkable presence. *Leptocylindrus danicus* in Melosiraceae was highest (49.4%) at U-do in November. Lower water temperature and higher salinity with highest concentration of PO_4-P (7.0 μg-at L^{-1}) and higher nitrogenous nutrients might be suitable for this species occurrence.

Chaetoceros species occurred at higher (33.1 to 34.6 psu) salinity with higher concentration of PO_4-P in all stations, but at Mara-do and U-do they grew more at the beginning of the spring, which could be possible that the nutrients were carried during winter through the Tsushima Current and became available for the uptake by this group.

In Dinophyceae group, *Prorocentrum* was the most abundant in August, and in comparison between the western and eastern coast, the occurrence of Dinophyceae was higher in the eastern coast of Jeju Island. Higher temperature (25.7°C) and the highest concentration of NO_3-N (39.0 μg-at L^{-1}) with higher concentration of PO_4-P might be the reason of this phenomenon. Phytoflagellates were found from spring to summer and *Chlamydomonas* sp. and Euglena sp. were common. Among coccolitophorids the observation of two warm-water species, *Calcidiscus leptoporus* at U-do and *Anoplosolenia brasiliensis* at Subji in July, suggests that the eastern coast might be strongly affected by Tsushima Current in summer rather than the western coast.

In summary it can be said that phytoplankton abundance was higher during spring at all stations with higher species diversity. Phytoplankton abundance was higher at Mara-do than at U-do and also higher from March to September with comparatively low salinity and high concentration of NO_3-N. At U-do the abundance was higher in spring followed by autumn with higher concentration of NH_4-N. At Mara-do pennate diatoms were more abundant during summer followed by spring owing to the influence of high concentration of NO_3-N and NH_4-N. Whereas at U-do centric diatoms were abundant in spring followed by early summer and early autumn with higher salinity and higher NO_3-N concentration. The observation of more abundant dinoflagellates and the occurrence of coccolithophorids in the eastern coast may be the new phenomena. Thus furthermore comprehensive study is necessary to understand exact relationships between the seawater current and newly observed species.

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