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# The Influence of Hydrography on the Distribution of Phytoplankton in the Southern Taiwan Strait

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During the period August 1985 to May 1986, phytoplankton in the southern Taiwan Strait was collected and studied for distributional variability in relation to hydrography. The results indicated that maximum standing crops of phytoplankton occurred in October and May due to the outgrowth of certain species of diatoms and blue-green algae. The majority of phytoplankton appeared in the water in the top 25 m and occurred in distinct clusters under the influence of water movement. Multivariate analysis indicated that hydrographic parameters, which accounted for the variability of phytoplankton distribution, varied seasonally. Vertical, spatial and temporal variabilities were also apparent. The close relationship between hydrography and algal distribution justifies the use of variations in the phytoplankton population as a useful tracer of water movement.

## Introduction

In an aquatic system, phytoplankton distribution is linked to the biotic and abiotic characteristics of the water. Phytoplankton may grow rapidly and demonstrate various responses to the environment in which they grow, resulting in high spatial heterogeneity. However, the source of variability is not easily discernible. Multivariate statistical analysis has been employed for this purpose in a few studies. Estrada and Blasco (1979), Blasco *et al.* (1980), Estrada (1984) and Matta and Marshall (1984) used principal-component analysis to relate upwelling processes to phytoplankton distribution. Holligan *et al.* (1980) and Maddock *et al.* (1981) used the correspondence analysis in dealing with dinoflagellates around the British Isles, whilst Moll and Rohlf (1984) combined multivariate and univariate analyses for salt marsh phytoplankton. All these studies demonstrated that multivariate analysis techniques are powerful tools for quantifying relationships between phytoplankton populations and their environment.

The hydrography of the southern Taiwan Strait has been intensively studied (e.g. Chu, 1963; Fan, 1982; Hung *et al.*, 1986). Three major currents flow over the south strait with very different features. The warm South China Sea Current moves northward into the strait when the south-west monsoon wind prevails in summer. During this period a



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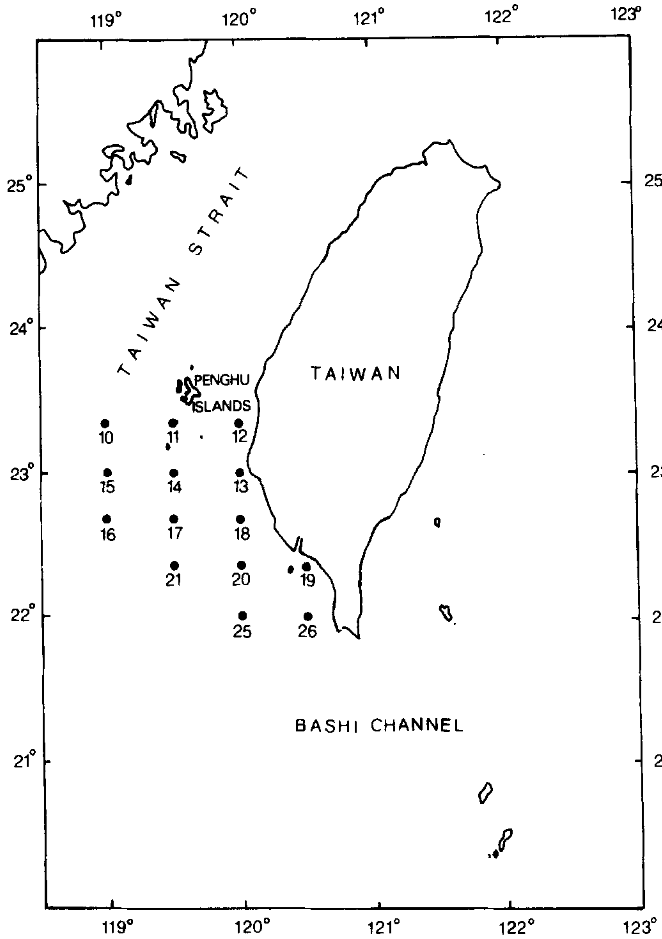


Figure 1. Map showing sampling locations in the southern Taiwan Strait.

branch of Kuroshio, also a warm current, passes through Bashi Channel and flows northward into the southern strait along the coast with relatively higher temperature and salinity. During autumn and winter this current encounters the southward flowing cold China Coastal Current in the vicinity of Penghu Islands and is then diverted southwestward into the South China Sea. Upwelling of deep water frequently occurs in late autumn and winter in the study area due to the interaction of waters flowing from opposite directions, the abrupt change of bottom topography, or the drift of surface water driven by strong north-east monsoon winds. Additionally, a large quantity of freshwater is discharged into the sea along the western coast, particularly in the rain and typhoon seasons from May to September. The consequent physical and chemical variability in those waters clearly influences the distribution patterns of marine organisms in the southern Taiwan Strait.

At the present time very little is known about phytoplankton in the southern Taiwan Strait. In a previous study the author investigated the seasonal standing crop and community structure of phytoplankton of this region (Huang, 1986), and in the present work particular attention has been given to the influence of hydrography on phytoplankton distribution using multivariate techniques.

TABLE 1. Factor loadings on hydrographic parameters and cell densities in different months

| | August | October | December | May |
|---|---|---|---|---|
| Factor 1 (%) | 37·2 | 59·9 | 50·3 | 31·8 |
| Depth | 0·749 | 0·774 | 0·421 | 0·366 |
| Temperature | −0·014 | −0·891 | −0·964 | 0·224 |
| Salinity | 0·569 | 0·893 | 0·855 | −0·181 |
| pH | −0·263 | −0·242 | −0·874 | −0·613 |
| Nitrite | 0·797 | −0·011 | −0·137 | 0·777 |
| Nitrate | 0·855 | 0·926 | 0·683 | 0·931 |
| Phosphate | 0·813 | 0·866 | 0·053 | 0·178 |
| Silicate | −0·033 | 0·902 | 0·707 | 0·776 |
| Log cells $l^{-1}$ | 0·052 | −0·161 | −0·145 | −0·025 |
| Factor 2 (%) | 14·7 | 15·1 | 13·8 | 20·2 |
| Depth | −0·341 | −0·256 | 0·161 | −0·214 |
| Temperature | 0·753 | 0·214 | −0·150 | 0·007 |
| Salinity | −0·428 | −0·112 | −0·065 | −0·742 |
| pH | 0·029 | 0·602 | −0·094 | 0·489 |
| Nitrite | 0·241 | 0·085 | 0·145 | −0·096 |
| Nitrate | −0·005 | −0·070 | 0·227 | 0·148 |
| Phosphate | 0·023 | −0·133 | 0·918 | −0·252 |
| Silicate | 0·012 | 0·501 | −0·244 | 0·217 |
| Log cells $l^{-1}$ | 0·737 | 0·805 | 0·303 | 0·831 |

## Materials and methods

The locations of 14 sampling stations off the south-western coast of Taiwan are shown in Figure 1 Some or all were visited on four occasions during the cruises of *Ocean Researcher I* from August 1985 to May 1986. On each visit the temperature and salinity of the water were recorded using a CTD instrument before the water was sampled. The light transmittance in water was determined with both a Secchi disc and a Li-Cor 185 desk unit equipped with an underwater sensor. At each station waters at depths of 3, 10, 25, 50, 75 and 100 m to the surface were collected separately with Niskin samplers. For phytoplankton studies, 1-l subsamples of water were preserved immediately after collection with Lugol's solution and stored in plastic bottles. The procedures of sample preparation and microscopic examination have been described previously (Huang, 1986). For nutrient study, water samples were stored at 5°C until they were analysed in the laboratory (not later than 10 days after collection). The detailed results of analysis have been reported in Hung *et al.* (1986), and these records of nutrient concentrations were used in the present study for comparison with phytoplankton data.

In the present study, statistical techniques were employed for both phytoplankton and hydrography data in order to simplify the complicated information and to allow easier interpretation of the variability within hydrographic and phytoplankton data. Factor analysis (Blackith & Reyment, 1971; Jöreskog *et al.*, 1976), a multivariate method of data reduction, is primarily used in the present study. In this analysis, all the relationships among variables are accounted for by relatively independent and interpretable, but nonobservable, factors. In order to simplify interpretation, it is common practice to rotate the factor axes after they have been established. The factor axes were rotated in an oblique process to a new position such that they best accorded with any distinct clusters of vectors

TABLE 2. List of phytoplankton taxa in the study area

Bacillariophyceae

*Achnanthes brevipes* Agardh
*A. longipes* Agardh
*Achnanthes* sp.
*Actinocyclus octonarius* Ehrenberg
*Actinocyclus* sp.
*Actinoptychus senarius* Ehrenberg
*A. splendens* (Shad.) Ralfs ex Pritchard
*Amphiprora alata* (Ehrenb.) Kützing
*A. gigantea* var. *sulcata* (O'meara) Cleve
*Amphiprora* sp.
*Amphora coffeaeiformis* (Agardh) Kützing
*A. costata* W. Smith
*A. cymbifera* Gregory
*A. lineolata* Ehrenberg
*A. ovalis* Kützing
*A. terroris* Ehrenberg
*Amphora* sp.
*Asterionella cleveanus* Grunow
*A. glacialis* Castracane
*Asterionella* sp.
*Asterolampra marylandica* Ehrenberg
*Asteromphalus heptactis* (Bréb.) Ralfs ex Pritchard
*Asteromphalus* sp.
*Bacillaria paxillifer* (Mull.) Hendey
*Bacteriastrum delicatulum* Cleve
*B. elongatum* Cleve
*B. hyalinum* Lauder
*B. hyalinum* var. *princeps* (Castr.) Ikari
*B. mediterraneum* Pavillard
*B. minus* Karsten
*B. varians* Lauder
*B. varians* var. *hispida* (Castr.) Schroder
*Biddulphia aurita* (Lyngb.) Brébisson
*B. granulata* Roper
*B. longicruris* var. *hyalina* (Schrod.) Cupp
*B. mobiliensis* (Bail.) Grunow ex Van Heurck
*B. obtusa* (Kütz.) Ralfs
*B. reticulum* (Ehrenb.) Boyer
*B. rhombus* (Ehrenb.) W. Smith
*B. sinensis* Greville
*B. tuomeyi* (Bail.) Roper
*Caloneis* sp.
*Cerataulina pelagica* (Cleve) Hendey
*Cerataulus smithii* Ralfs ex Pritchard
*Chaetoceros affine* Lauder
*C. atlanticum* Cleve
*C. atlanticum* var. *neapolitana* (Schrod.) Hustedt
*C. atlanticum* var. *skeleton* (Schutt) Hustedt
*C. breve* Schutt
*C. compressum* Lauder
*C. concavicorne* Mangin
*C. constrictum* Gran
*C. convolutum* Castracane
*C. curvisetum* Cleve
*C. decipiens* Cleve
*C. densum* Cleve
*C. didymum* Ehrenberg
*C. didymum* var. *anglica* (Grun.) Gran
*C. distans* Cleve
*C. diversum* Cleve
*C. indicum* Karsten
*C. janischianum* Castracane
*C. laciniosum* Schutt
*C. laevis* Leuduger-Fortmorel
*C. lauderi* Ralfs
*C. lorenzianum* Grunow
*C. messanense* Castracane
*C. muelleri* Lemmermann
*C. pelagicus* Cleve
*C. pendulus* Karsten
*C. peruvianum* Brightwell
*C. pseudocurvisetum* Mangin
*C. setoensis* Ikari
*C. subsecundum* (Grun.) Hustedt
*C. teres* Cleve
*Chaetoceros* pl. sp.
*Climacodium biconcavum* Cleve
*C. frauenfeldianum* Grunow
*Climacodium* sp.
*Climacosphenia moniligera* Ehrenberg
*Climacosphenia* sp.
*Cocconeis pediculus* Ehrenberg
*C. placentula* Ehrenberg
*C. scutellum* Ehrenberg
*Cocconeis* sp.
*Corethron criophylum* Castracane
*Coscinodiscus asteromphalus* Ehrenberg
*C. centralis* Ehrenberg
*C. concinnus* W. Smith
*C. gigas* Ehrenberg
*C. granii* Gough
*C. kützingii* Schmidt
*C. lineatus* Ehrenberg
*C. marginatus* Ehrenberg
*C. nitidus* Gregory
*C. nodulifera* Janisch ex Schmidt
*C. radiatus* Ehrenberg
*C. rothii* (Ehrenb.) Grunow
*C. subtilis* Ehrenberg
*C. wailesii* Gran et Angst
*Coscinodiscus* pl. sp.
*Cyclotella striata* (Kütz.) Grunow
*C. stylorum* Brightwell
*Cyclotella* sp.
*Cymbella affine* Kützing
*Dactyliosolen mediterraneus* Peragallo
*Diatoma hyalinum* Kützing
*Diatoma* sp.
*Diploneis bombus* Ehrenberg
*D. fusca* (Greg.) Cleve
*D. fusca* var. *hyperborea* (Grun.) Hustedt
*D. splendida* (Greg.) Cleve
*Diploneis* sp.
*Ditylum sol* Grunow
*Eucampia cornuta* (Cleve) Grunow
*E. zoodiacus* Ehrenberg
*Fragilaria oceanica* Cleve
*Fragilaria* sp.

TABLE 2. (*Continued*)

| | |
|---|---|
| *Gomphonema* sp. | |
| *Gossleriella tropica* Schutt | |
| *Grammatophora marina* (Lyngb.) Kützing | |
| *Guinardia flaccida* (Castra.) Peragallo | |
| *Gyrosigma balticum* (Ehrenb.) Cleve | |
| *Gyrosigma* sp. | |
| *Hemiaulus hauckii* Grunow ex Van Heurck | |
| *H. sinensis* Greville | |
| *Hemidiscus* sp. | |
| *Hyalodiscus stelliger* Bailey | |
| *H. subtilis* Bailey | |
| *Lauderia borealis* Gran | |
| *Leptocylindrus danicus* Cleve | |
| *Licmophora abbreviata* Agardh | |
| *Licmophora* sp. | |
| *Lithodesmium undulatum* Ehrenberg | |
| *Mastogloia* sp. | |
| *Melosira distans* (Ehrenb.) Kützing | |
| *M. jurgensii* Agardh | |
| *M. moniliformis* (Mull.) Agardh | |
| *M. nummuloides* (Dillw.) Agardh | |
| *Melosira* sp. | |
| *Navicula angusta* Grunow | |
| *N. cancellata* Donkin | |
| *N. clavata* Gregory | |
| *N. directa* (W. Sm.) Cleve | |
| *N. distans* (W. Sm.) Cleve | |
| *N. forcipata* Greville | |
| *N. humerosa* Brébisson | |
| *N. lanceolata* (Agardh) Kützing | |
| *N. membranacea* Cleve | |
| *N. monilifera* Cleve | |
| *N. perrhombus* Hustedt | |
| *N. tuscula* (Ehrenb.) Van Heurck | |
| *Navicula* pl. sp. | |
| *Nitzschia acuminata* (W. Sm.) Cleve | |
| *N. angularia* W. Smith | |
| *N. closterium* (Ehrenb.) W. Smith | |
| *N. delicatissima* Cleve | |
| *N. fonticola* Grunow | |
| *N. frustulum* (Kütz.) Grunow | |
| *N. gracilis* Hantzsch | |
| *N. hungarica* Grunow | |
| *N. lanceolata* W. Smith | |
| *N. littoralis* Grunow | |
| *N. longissima* (Bréb.) Ralfs ex Pritchard | |
| *N. longissima* var. *reversa* Grunow | |
| *N. marginulata* Grunow | |
| *N. marina* Grunow | |
| *N. panduriformis* Gregory | |
| *N. panduriformis* var. *intermedia* Grunow | |
| *N. seriata* Cleve | |
| *N. sigma* (Kütz.) W. Smith | |
| *N. sigma* var. *intermedia* W. Smith | |
| *N. spathulata* Brébisson ex W. Smith | |
| *N. tryblionella* Hantzsch | |
| *N. vitrea* Norman | |
| *Nitzschia* pl. sp. | |
| *Paralia sulcata* (Ehrenb.) Cleve | |
| *Pinnularia* sp. | |
| *Planktoniella sol* (Wall.) Schutt | |
| *Pleurosigma affine* Grunow | |
| *P. angulatum* var. *strigosa* (W. Sm.) Cleve | |
| *P. fasciola* (Ehrenb.) W. Smith | |
| *P. intermedium* W. Smith | |
| *P. naviculaceum* Brébisson | |
| *P. normani* Ralfs | |
| *P. pelagicum* Peragallo | |
| *P. rigidum* var. *incurvata* Grunow | |
| *P. strigosum* W. Smith | |
| *Pleurosigma* sp. | |
| *Podosira stelliger* (Bail.) Mann | |
| *Rhabdonema adriaticum* Kützing | |
| *R. arcuatum* (Lyngb.) Kützing | |
| *Rhizosolenia acuminata* (Perag.) Gran | |
| *R. alata* Brightwell | |
| *R. bergonii* Peragallo | |
| *R. castracanei* Peragallo | |
| *R. crassispina* Schroder | |
| *R. cylindrus* Cleve | |
| *R. delicatula* Cleve | |
| *R. fragilissima* Bergon | |
| *R. hebetata* Bailey | |
| *R. imbricata* Brightwell | |
| *R. robusta* Norman ex Pritchard | |
| *R. setigera* Brightwell | |
| *R. stolterfothii* Peragallo | |
| *R. styliformis* Brightwell | |
| *R. styliformis* var. *latissima* Brightwell | |
| *Rhizosolenia* sp. | |
| *Schroederella delicatula* (Perag.) Pavillard | |
| *Skeletonema costatum* (Grev.) Cleve | |
| *Stauroneis amphioxys* Gregory | |
| *Stephanopyxis nipponica* Gran et Yendo | |
| *S. palmeriana* (Grev.) Grunow | |
| *Stigmophira rostrata* Wallich | |
| *Striatella unipunctata* (Lyngb.) Agardh | |
| *Surirella americana* Peragallo | |
| *S. fastuosa* Ehrenberg | |
| *Surirella* sp. | |
| *Synedra fasciculata* (Agardh) Kützing | |
| *S. gaillonii* (Bory) Ehrenberg | |
| *S. ulna* (Nitzsch) Ehrenberg | |
| *S. ulna* var. *danica* (Kütz.) Grunow | |
| *Synedra* sp. | |
| *Thalassionema nitzschioides* Hustedt | |
| *Thalassiosira baltica* (Grun.) Ostenfeld | |
| *T. condensata* Cleve | |
| *T. decipiens* (Grun.) Jörgensen | |
| *T. eccentrica* (Ehrenb.) Cleve | |
| *T. gravida* Cleve | |
| *T. hyalina* (Grun.) Gran | |
| *T. nordenskiold* Cleve | |
| *T. pacifica* Gran et Angst | |
| *T. rotula* Meunier | |
| *Thalassiosira* pl. sp. | |
| *Thalassiothrix frauenfeldii* Grunow | |
| *T. longissima* Cleve et Grunow | |
| *T. mediterranea* var. *pacifica* Cupp | |
| *Trachyneis aspera* (Ehrenb.) Cleve | |

TABLE 2. (*Continued*)

| | |
|---|---|
| *T. aspera* var. *elliptica* Hendey | *P. triestinum* Schiller |
| *Triceratium favus* Ehrenberg | *Protoperidinium abei* (Abe) Paulsen |
| *T. formosum* Brightwell | *P. achromaticum* (Lev.) Balech |
| *T. reticulum* Ehrenberg | *P. balticum* (Lev.) Lemmermann |
| *Triceratium* sp. | *P. cerasus* (Pauls.) Balech |
| Dinophyceae | *P. decipiens* (Jorg.) Parke et Dodge |
| *Ceratium candelabrum* (Ehrenb.) Stein | *P. depressum* (Bail.) Balech |
| *C. furca* (Ehrenb.) Claparede et Lachmann | *P. faeoceros* Paulsen |
| *C. lineatum* (Ehrenb.) Cleve | *P. granii* (Ost.) Balech |
| *C. macroceros* var. *gallicum* (Kof.) Jörgensen | *P. islandicum* (Pauls.) Balech |
| *C. massiliense* (Gourr.) Jörgensen | *P. marukawai* Abe |
| *C. pentagonum* Gourret | *P. oceanicum* (Vanhoffen) Balech |
| *C. teres* Kofoid | *P. pentagonum* (Gran) Balech |
| *Ceratium* pl. sp. | *P. pyriforme* (Pauls.) Balech |
| *Cladophyxis brachiolata* Stein | *P. subinerme* (Pauls.) Loeblich III |
| *Cochlodimium* sp. | *P. thorianum* (Pauls.) Balech |
| *Dinophysis* sp. | *Protoperidinium* sp. |
| *Glenodinium foliaceum* Stein | *Pyrocystis lunula* Schutt |
| *Glenodinium* sp. | *P. lanceolata* Murray |
| *Gonyaulax polygramma* Stein | *P. noctiluca* Murray |
| *G. turbynei* Murray et Whitting | *Scrippsiella trochoidea* (Stein) Loeblich |
| *Gymnodinium arcuatum* Kofoid | *Warnowia parva* (Lohm.) Lindemann |
| *G. ochraceum* Kofoid et Swezy | Prymnesiaceae |
| *G. rhomboides* Schutt | *Chrysochromulina* sp. |
| *G. sanquineum* Hirasaka | Chrysophyceae |
| *G. vestifici* Schutt | *Dictyocha fibula* Ehrenberg |
| *Gymnodinium* sp. | *Distephanus speculum* (Ehrenb.) Hackel |
| *Gyrodinium spirale* (Bergh) Kofoid et Swezy | *Mesocena* sp. |
| *Noctiluca scintillans* (Macartn.) Ehrenberg | Cyanophyceae |
| *Ornithocercus* sp. | *Anabaena* sp. |
| *Oxytoxum gladiolus* Stein | *Pelagothrix clevei* Schmidt |
| *O. scolopax* Stein | *Richelia intracellularis* Schmidt |
| *O. reticulatum* (Stein) Butschi | *Spirulina* sp. |
| *O. tesselatum* (Stein) Schutt | *Trichodesmium contortum* Wille |
| *Oxytoxum* sp. | *T. erythraeum* Ehrenberg |
| *Prorocentrum micans* Ehrenberg | *T. thiebautii* Gomont |
| *P. triangulatum* Martin | |

representing variables (Harbaugh & Merriam, 1968; Jöreskog *et al.*, 1976). Because a large number of species occurred only occasionally and did not offer much useful ecological information, a criterion of selection of species was established before computation. A species selected for the analysis had a frequency of occurrence in greater than 15% of the total samples in the whole year's collections, irrespective of its abundance in particular samples. In addition, the variability caused by the absence of species included in the analysis was reduced by using logarithmic transformation of counting values (Estrada & Blasco, 1979). That is $X \rightarrow \log(X+1)$, where $X$ is the number of a species in 1 l of seawater. However, this transformation was not applied to hydrographic data. Multiple-regression and cluster analysis were also done on transformed data as an aid to the interpretation of phytoplankton distribution.

## Results and discussion

### *Analysis of hydrographic data*

Preliminary factor analysis based on 287 samples of entire collections yielded the first two most important factors, however, these factors did not explain as much variability as

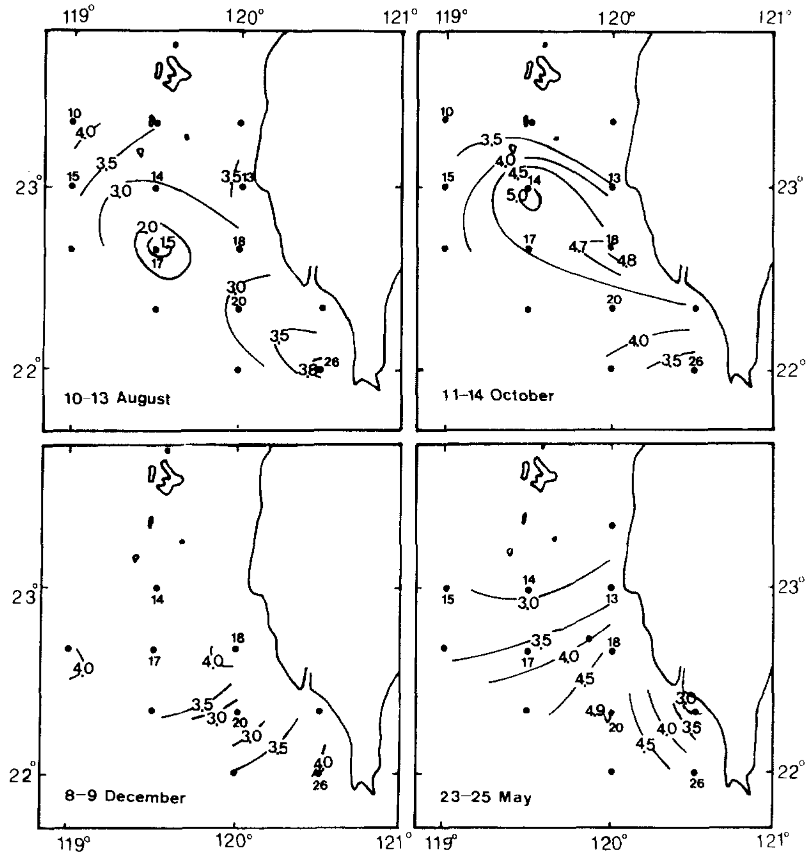

Figure 2. Distribution of blue-green algae in the top 25 m of the water (averaged log cell number $l^{-1}$).

expected, nor did the seasonal sequence of distribution. For this reason the subsequent factor analysis was done on the data collected on individual cruises (Table 1). Obviously, loadings on hydrographic parameters were variable with season. The first two factors explained more than 51% of total variability. For factor 1, the loading on temperature was extremely low in August because the whole strait water was occupied by northward flowing warm currents in summer (Chu, 1963; Fan, 1982). With October data, factor 1 accounted for 60% of total variability. This factor is referred to as the water-mass factor that can be deduced from high negative loading on temperature and positive loadings on salinity and nutrients. Furthermore, the high loading on depth suggested the stratification of waters in the study area. The result of the following Q-model factor analysis (Harbaugh & Merriam, 1968; Klovan & Imbrie, 1971; Jöreskog *et al.*, 1976), correlating hydrographic environments in terms of the phytoplankton species composition which they possess, supports this phenomenon. However, the present factor analysis failed to demonstrate the variability explained by the high-temperature and high-salinity Kuroshio water. It could be that Kuroshio water gradually loses its characteristics as it enters the strait and mixes with other waters. The influence of water mass on the factor 1 became very evident during the winter period, yet the upwelling determined from *T–S* and nutrient diagrams (Fan, 1982; Hung *et al.*, 1986) was not detectable. The fact is that the upwelling was restricted to small areas and not comparable with other water movements in the

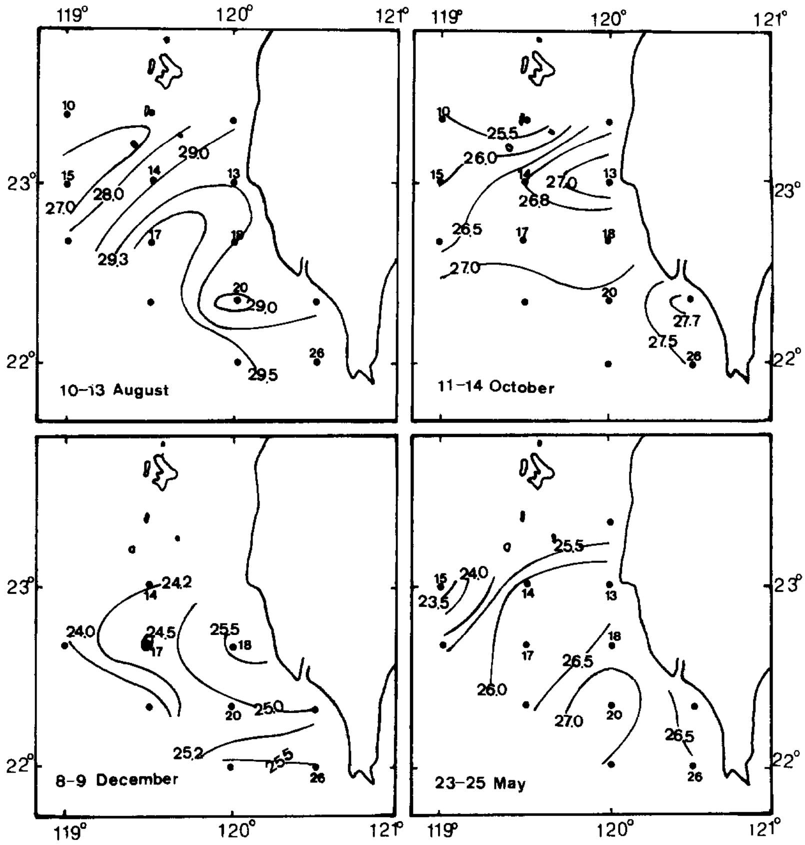


Figure 3. Distribution of temperatures in the top 25 m of the water (°C).

whole study area. Correlation between upwelling and phytoplankton distribution has also been shown by Estrada and Blasco (1979), Blasco *et al.* (1980) and Estrada (1984) using principal-component analysis. In May, pH and nutrients, which relate to biological activity, accounted for the largest portion of the total variability.

Factor 2 accounted from 13·8–20·2% of the total variability (Table 1). This factor, except in December, was strongly influenced by algal activity represented mainly by the blue-green alga. *Pelagothrix clevei* in August and diatoms *Thalassionema nitzchioides*, *Thalassiothrix frauenfeldii*, *Thalassiosira condensata*, *T. rotula* and *Bacteriastrum hyalinum* in October. In May, high positive loading on algal density and negative loading on salinity indicated that the discharge of freshwater into the sea was important to algal distribution, particularly in the coastal area.

In the factor analysis, high loadings on both phytoplankton density and hydrographic parameters for the same factor do not necessarily mean that they were significantly correlated. In the present study their correlation was determined by multiple regression with the stepwise method at $p < 0{\cdot}05$ using the $F$-test. It appeared that temperature was the sole parameter influencing algal abundance in August, whilst both temperature and salinity were important to algal distribution in October and December. The spring outburst of phytoplankton was closely related to pH, salinity, silicate, depth and nitrate. The above results agree with those of the previous factor analysis in the explanation of seasonal variations of hydrography and phytoplankton.

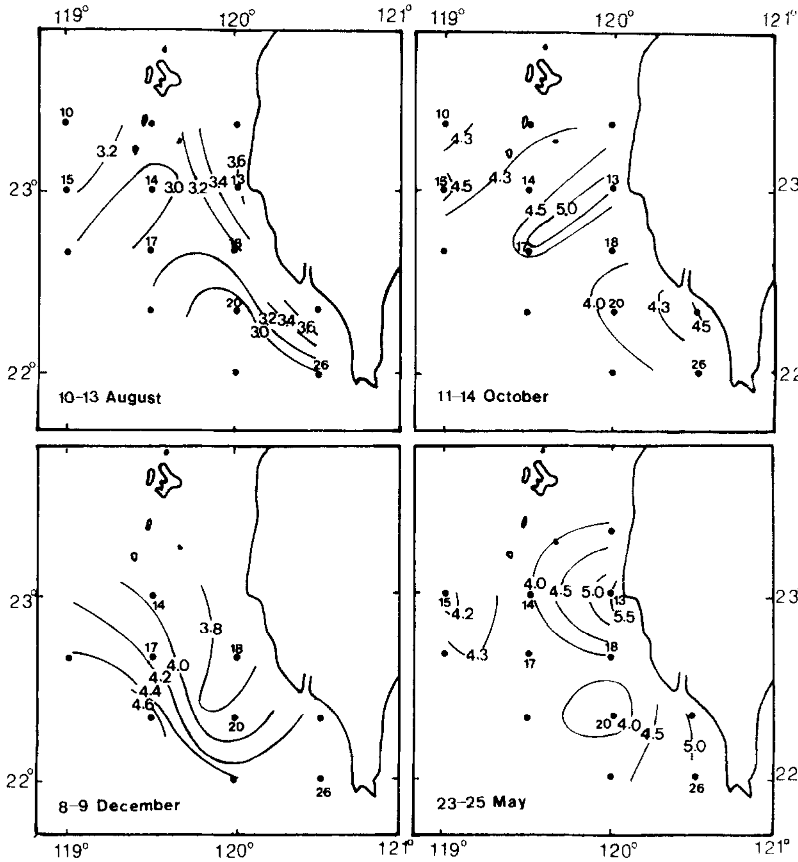


Figure 4. Distribution of diatoms and dinoflagellates in the top 25 m of the water (averaged log cell number $l^{-1}$).

### *Phytoplankton assemblages in the study area*

A total of more than 300 species and varieties of phytoplankton were obtained from the study area, of which 255 species were diatoms and 55 and seven species were dinoflagellates and blue-green algae, respectively (Table 2). The flora did not change significantly as compared with that in the previous year (Huang, 1986). A large number of species occurred in less than 15 of all samples and accounted for less than 20% of all the standing crop in cell numbers. These rare species contributed very little ecological information to the present study. Whilst species of *Bacteriastrum, Chaetoceros, Coscinodiscus* and *Thalassiosira, Thalassionema nitzschioides* and *Thalssiothrix frauenfeldii* were the most abundant in the populations; they contributed from 5% to 15% of the total standing crops. In summer and autumn, higher standing crops of phytoplankton at some stations often represented a higher proportion of blue-green algae to diatoms and flagellates. The main blue-green algae were *Pelagothrix clevei* and *Trichodesmium erythraeum*. Very few dinoflagellates and other small flagellates were observed in the samples; most of them were *Protoperidinium, Glenodinium* and *Ceratium*.

Maximum standing crops of phytoplankton occurred in October and May due to the outgrowth of certain species of blue-green algae and diatoms. The majority of phytoplankton appeared in the water layer within 25 m of the surface. The light intensity at 25 m

TABLE 3. Phytoplankton occurring in at least 15% of all samples; taxa selected for monthly factor analysis (O, October; M, May)

| | |
|---|---|
| 1. *Achnanthes* sp. (M) | 27. *Nitzschia* pl. sp. (O,M) |
| 2. *Amphora* sp. | 28. *Paralia sulcata* |
| 3. *Bacillaria paxillifer* | 29. *Pleurosigma affine* (O) |
| 4. *Bacteriastrum hyalinum* (O,M) | 30. *Rhizosolenia alata* (M) |
| 5. *B. varians* (M) | 31. *R. bergonii* |
| 6. *Chaetoceros affine* (O) | 32. *R. crassispina* (O,M) |
| 7. *C. curvisetum* (M) | 33. *R. imbricata* (O) |
| 8. *C. decipiens* (O) | 34. *Skeletonema costatum* (M) |
| 9. *C. lorenzianum* (O,M) | 35. *Synedra* sp. (M) |
| 10. *C. messanense* | 36. *Thalassionema nitzschioides* (O,M) |
| 11. *Chaetoceros* pl. sp. (O,M) | 37. *Thalassiosira baltica* |
| 12. *Coscinodiscus lineatus* (O) | 38. *T. condensata* (O,M) |
| 13. *Coscinodiscus* pl. sp. (O,M) | 39. *T. decipiens* |
| 14. *Diploneis* sp. | 40. *T. gravida* (O) |
| 15. *Eucampia cornuta* | 41. *T. hyalina* (O) |
| 16. *E. zoodiacus* | 42. *T. pacifica* (O) |
| 17. *Fragilaria ocenica* (O) | 43. *T. rotula* (O,M) |
| 18. *Hemiaulus hauckii* (O,M) | 44. *Thalassiosira* pl. sp. (O,M) |
| 19. *Lauderia borealis* (M) | 45. *Thalassiothrix frauenfeldii* (O,M) |
| 20. *Melosira* sp. | 46. *Triceratium* sp. (M) |
| 21. *Navicula* pl. sp. (O,M) | 47. *Dictyocha fibula* (O,M) |
| 22. *Nitzschia closterium* (O) | 48. *Distephanus speculum* (M) |
| 23. *N. longissima* | 49. *Glenodinium* sp. |
| 24. *N. panduriformis* (M) | 50. *Pelagothrix clevei* (O,M) |
| 25. *N. seriata* (O,M) | 51. *Trichodesmium thiebautii* (O,M) |
| 26. *N. sigma* | |

of most sampling stations decreased less than 10% of the incident light at the surface. Therefore, algal densities in the upper 25 m were used to illustrate the distribution pattern of phytoplankton. From Figure 2 it can be seen that blue-green algae and diatoms appeared in the north-westward direction off the south-west coast of Taiwan which is consistent with the movement of the Kuroshio and South China Sea currents (Figure 3). Maximum amounts were found at station 14 in October and at station 20 in May, respectively. The close relationship between temperature and blue-green alga distribution has been indicated previously (Huang, 1986). Figure 4 shows that both diatoms and dinoflagellates were abundant at stations 13, 14, 15, 17 and 26 in these two months. In December, the cold water moved down from the north as shown in Chu (1963), Fan (1982) and Figure 3, and so most phytoplankton occurred southward of and near station 25. During the summer period the phytoplankton were relatively homogenous in the study region.

### *Analysis of phytoplankton data*

From the whole year's collections, 51 taxa (Table 3) were selected for both factor and cluster analyses. These species occurred in at least 15% of all samples (287), regardless of their abundance. In the preliminary results of the factor analysis based on the entire data most species which were dominant throughout the year did not contribute significantly to the variability; therefore, they reduced the seasonal variation. In order to avoid the multimonth variability as shown in Estrada (1984), and to facilitate interpretation, the subsequent factor analysis was based on each of the monthly collections. Twenty-seven taxonomic groups (Table 3) selected from October and May assemblages were included in

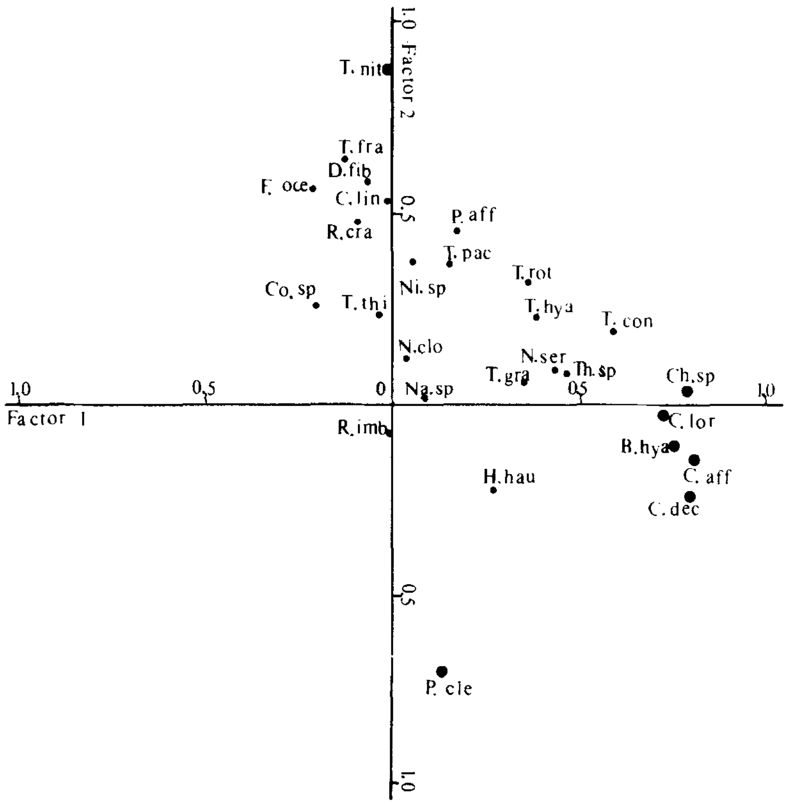


Figure 5. The positions of 27 species vectors on the first two factors produced from October assemblages. Abbreviations refer to the species names in Table 3.

the analysis. These species occurred in at least 20% of all samples taken on each cruise. Figure 5 clearly shows three clusters of species strongly influencing the first two axes in October. *Chaetoceros affine* together with *C. decipens*, *C. lorenzianum*, *Chaetoceros* sp. and *Bacteriastrum hyalinum*, form a cluster and accounted for the major portion of the total variability of factor 1. Examination of the basic data showed that these taxa were plentiful in observed assemblages, especially at station 13. *Thalassionema nitzschioides*, which was abundant in the offshore area of stations 15 and 16, formed the second cluster and strongly influenced factor 2. The third cluster was occupied by *Pelagothrix clevei* only in the negative side of factor 2; this is an alga which predominated at station 14. The rest of the species contributed relatively less variability to the first two factors. With May data (Figure 6) *Nitzschia seriata*, *Skeletonema costatum*, *Chaetoceros lorenzianum*, *Thalassiosira condensata* and *Lauderia borealis* strongly influenced factor 1, and *Thalassiothrix frauenfeldii*, *Thalassionema nitzschioides* and *Chaetoceros curvisetum* influenced factor 2 in opposite directions. These diatoms were dominant at station 12, 13, 19 and 26. Blue-green algae explained the lower May variability, although they were abundant at station 20. The above results revealed seasonal and spatial variations of the main taxa. Nevertheless, in multivariate analysis phytoplankton species which have high loadings in the same cluster may not necessarily occur together frequently (Maddock *et al.*, 1981). Therefore, interpretation of the results of the analysis must be made with caution.

The geographic pattern of phytoplankton distribution can be detected when seasonal variation is removed from the multivariate analysis (Matta & Marshall, 1984). In the

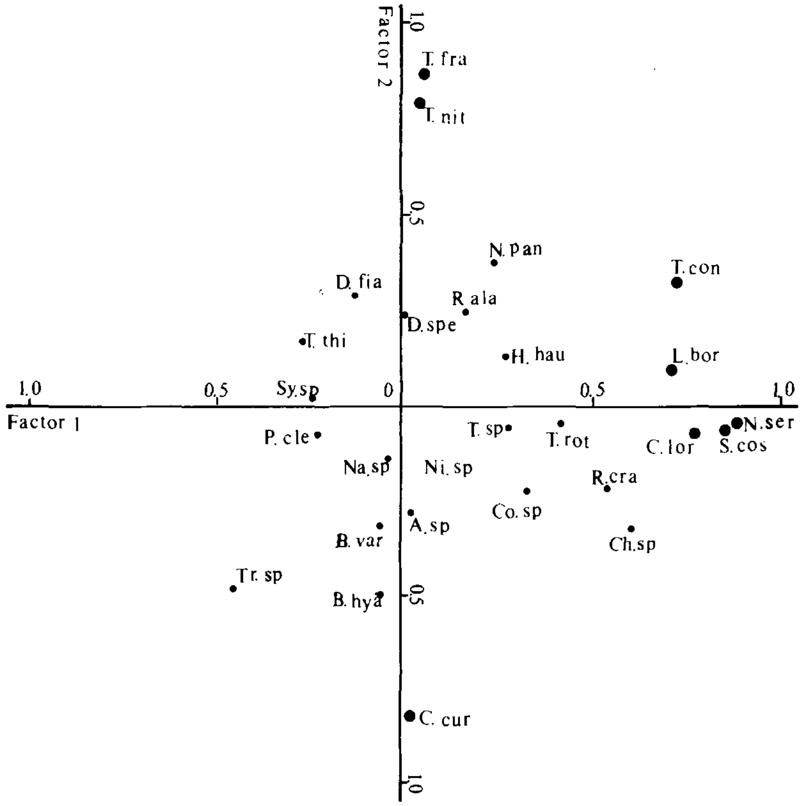


Figure 6. The positions of 27 species vectors on the first two factors produced from May assemblages. Abbreviations refer to the species names in Table 3.

TABLE 4. Loadings of the first factor on sampling stations and depths in October and May

| Station No. | Depth (m) October 1985 3 | 10 | 25 | May 1986 3 | 10 | 25 |
|---|---|---|---|---|---|---|
| 10 | 0·125 | 0·116 | 0·092 | — | — | — |
| 11 | 0·113 | 0·028 | 0·088 | — | — | — |
| 12 | 0·666 | 0·422 | 0·607 | −0·108 | 0·327 | −0·048 |
| 13 | 0·777 | 0·766 | 0·847 | −0·089 | −0·071 | 0·135 |
| 14 | 0·833 | 0·924 | 0·847 | 0·362 | 0·290 | 0·843 |
| 15 | 0·079 | 0·185 | 0·656 | −0·043 | −0·182 | 0·069 |
| 16 | 0·710 | 0·873 | 0·757 | 0·141 | 0·183 | 0·657 |
| 17 | 0·223 | 0·299 | 0·607 | 0·730 | 0·618 | 0·825 |
| 18 | 0·850 | 0·722 | −0·068 | 0·791 | 0·947 | 0·891 |
| 19 | −0·133 | −0·141 | 0·095 | 0·046 | 0·027 | −0·110 |
| 20 | 0·345 | −0·083 | 0·688 | 0·922 | 0·943 | 0·944 |
| 21 | 0·512 | 0·840 | 0·908 | 0·945 | 0·767 | 0·941 |
| 25 | −0·048 | 0·822 | 0·144 | 0·833 | 0·882 | 0·942 |
| 26 | 0·190 | 0·398 | 0·342 | 0·481 | 0·522 | 0·214 |

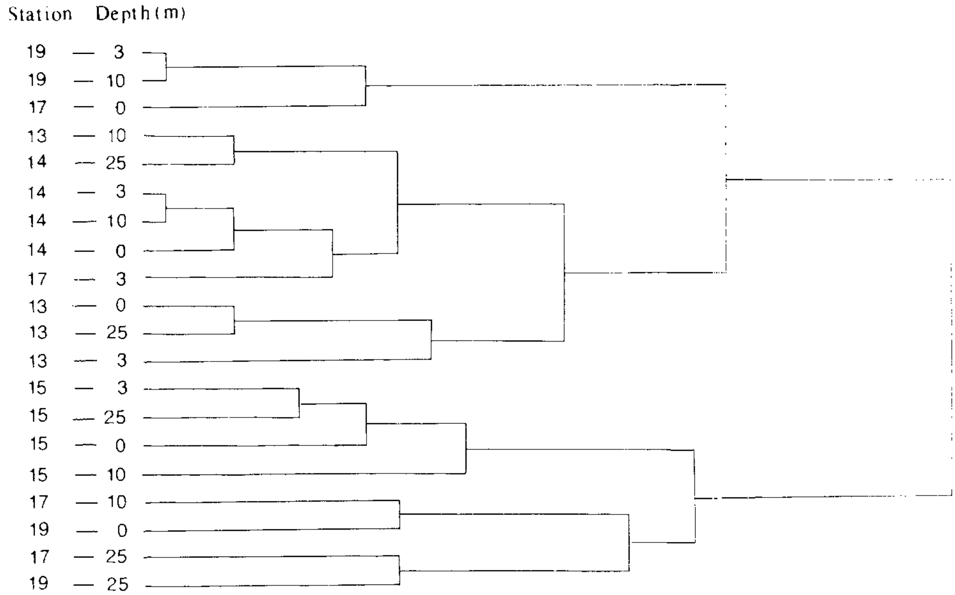


Figure 7. Dendrogram showing clusters of phytoplankton populations collected from different depths at five stations in October 1985.

Q-model analysis, based on 51 taxonomic groups, the variabilities explained by locations were evidently different. It appears that stations 13, 14, 16 and 21 had higher cell densities (Figure 4) and, therefore, contributed a larger portion of variability to factor 1 in October, whilst stations 20, 21, 25, 17 and 18 accounted for the variability in May (Table 4). According to the species composition of assemblages, the former can be referred to as the diatom factor and the latter as the blue-green alga factor. In addition, highly variable loadings with depths were also found in some small areas, for example at stations 18 and 25 in October and at stations 14 and 16 in May. It is of particular interest that loadings at 3 and 10 m at station 18 were very high, but negligible at 25 m in October. This was probably related to the upwelling of deep water to the subsurface layer (the temperature at 25 m was more than 2°C lower than at the surface) as shown in Hung *et al.* (1986). Therefore, the vertical variability of the phytoplankton population can reflect stratification or vertical movement of water in certain areas.

The close relationship between the species composition of phytoplankton and water movement has been shown previously (Estrada & Blasco, 1979; Estrada, 1984). The similarity between two algal populations can be determined on the basis of the species present. Thus it can be assumed that the higher the similarity between two phytoplankton populations, the closer the characteristics of the two water regimes. Because of the very complicated hydrography in October, phytoplankton populations at five major stations in that month were examined by grouping into clusters based on 51 taxonomic groups (Table 3). The results of both the factor and the cluster analyses were quite similar. As shown in the dendrogram of cluster analysis (Figure 7), four clusters appeared in the last three large distances. Populations at stations 13 and 14 combined into a cluster, while those at station 15 in the offshore area formed an isolated cluster. The first cluster appeared in the high-temperature regime (27·0 ± 0·3°C) that was possibly a mixture of Kuroshio and local coastal waters, and the second cluster in the colder regime (25·8 ± 0·1°C) under the influence of the southward flowing China Coastal Current. Examination of the species composition of clusters also showed different major taxa. Separate clustering of stations 17 and 19 at both ends of the dendrogram was attributed to the discontinuity of water movement, which again resulted from the upwelling near two stations as mentioned above.

It is concluded that multivariate analysis provides ecologically significant information in the interpretation of phytoplankton distribution under the influence of hydrography. Vertical, spatial and temporal variabilities of small-scale data (monthly collections) were apparent in the present study. The above results show that the distribution of different phytoplankton populations can be a useful tracer of water movement.

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