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Effects of Surrounding Physical and Chemical Environment on the Spatial Heterogeneity in Phytoplankton Communities of Hiroshima Bay, Japan

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ABSTRACT

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The surface waters of Hiroshima Bay, a large coastal embayment subject to marked eutrophication, were sampled over a three month period. Important aspects of *in situ* environmental heterogeneity include (1) the phytoplankton community, which is sensitive to variations in environmental conditions, and (2) the surrounding physical and chemical environment as habitat for the phytoplankton community. Two multivariate analyses were used to elucidate spatial relationships between these two environmental heterogeneities. Cluster analyses based on phytoplankton composition indicated three different water masses that approximately correspond to the northern, western, and central-to-southern parts of the bay. Multiple discriminant analysis in water quality indicated that spatial differences in phytoplankton composition throughout the bay were a primary response of the phytoplankton community to *in situ* spatial variations in the physical and chemical environment as represented by water quality.

ADDITIONAL INDEX WORDS: *Aquatic ecosystem, environmental heterogeneity, phytoplankton community, semi-enclosed coastal bay, water quality, multivariate analysis.*

INTRODUCTION

Due mainly to tidal mixing, river inputs and the morphometric features of a water body, environmentally heterogenous areas with a variety of physical, chemical, and biological characteristics are frequently formed spatially and temporally in estuarine and coastal water bodies. This situation is particularly marked in semi-enclosed coastal embayments such as Hiroshima Bay, where there is limited water exchange and increasing exposure to environmental stresses induced by human activities. Thus, for the development of programs for water resource management and available utilization of such aquatic ecosystems, it is becoming increasingly necessary to make allowance for *in situ* spatial heterogeneity of the environment. In addition, it is of interest to elucidate whether ecological relationships exist between the distributional patterns in the aquatic organism community present and the *in situ* heterogeneity of the surrounding environment.

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In general, aquatic ecosystems may be described in terms of (1) aquatic organism communities and (2) the surrounding abiotic (physical and chemical) habitat. Consequently, heterogeneity of aquatic ecosystems is approachable from these two viewpoints. Of the various types of aquatic organism communities, the phytoplankton community was selected as primary indicators of changes in the surrounding environments, especially in view of its place in the food web and becuase of its high adaptability or high sensitivity to varying environmental conditions among organism communities. Parameters of water quality, *e.g.*, water temperature and salinity, were studied because they characterize conditions of the physaical environment. Dissolved inorganic nitrogen (DIN) and phosphorus (DIP), primarily important anthropogenic substances in eutrophicated coastal water bodies, are also considered in this study. These water qualities are also major factors that control algal growth and hence affect the distribution of the phytoplankton community in estuaries and other coastal waters.

The major purpose of this study is to thus clarify the degree to which the phytoplankton community responds to the surrounding environment, particularly from the viewpoint of spatial heterogeneity of aquatic ecosystems on a macro scale. In complex environments such as estuarine and coastal ecosystems, spatially unidirectional gradients of various environmental factors are not always evident, presumably due to complex interactions among various factors. Therefore, of the various multivariate analyses widely used in ecological work, the procedure proposed by GREEN and VASCOTTO (1978) was applied as a means: *in situ* spatial heterogeneity in the phytoplankton community was identified by cluster analysis based on the phytoplankton composition. Further, multiple discriminant analysis (canonical analysis) of the surrounding environment, with respect to water quality as a phytoplankton habitat, was conducted over a wide area in Hiroshima Bay, Japan. Results of these statistical procedures provided useful information for understanding and describing eutrophication processes in Hiroshima Bay (MUKAI *et al.*, 1985).

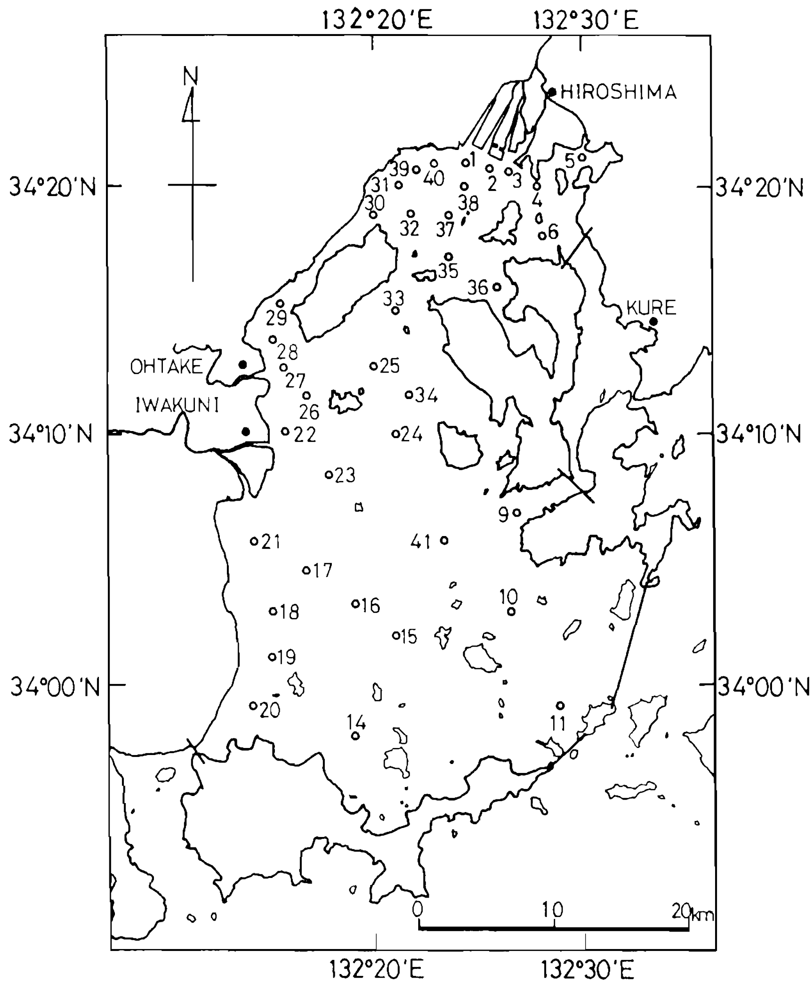

Figure 1. Hiroshima Bay, Japan. Numbers indicate the number of sampling stations.

STUDY AREA

Hiroshima Bay (Figure 1), situated on the western part of the Seto Inland Sea, is a typical example of the semi-enclosed coastal embayment which has a surface area of about 946 km^2, a volume of about 24.2×10^9 m^3, and an average depth of 25.6 m. The mean freshwater discharge into the bay is about 149×10^5 m^3d^{-1}. The northern part of Hiroshima Bay, the most enclosed region of the bay, receives large amounts of municipal-industrial effluents generated in Hiroshima City (population is about one million) either directly or through the Ohta River. This area is thus the most polluted and eutrophicated compared to other parts of the bay. Red tides also frequently occur in this area. In the western part of Hiroshima Bay, treated sewage waters are discharged mainly from oil refineries, petrochemical, textile, pulp and paper industries in the Iwakuni-Ohtake industrialized regions located on the west coast of the bay. The central to southern parts of the bay contrast with these areas because it is largely free from land-based sources of pollution. This southern area is only subject to secondary pollution associated with currents within the bay. Although data relating to the loading of major nutrients that stimulate algal growth are very scarce, the equivalent of about 31.91 tons of total nitrogen per day and 3.56 tons of total phosphorus per day entered the bay (whole-bay basis) in 1977. These figures were provided by the Hiroshima prefectural authorities.

Hiroshima Bay has low flushing characteristics due to limited water exchange capacity with neighboring seas through the channels of the extreme southern part of the bay. An average period in which a parcel of water remains within the bay was estimated to be of the order of 151 tidal cycles, or approximately 76 days. This observation is based on tracking miniature floating balls and tracing the path of dyes using the large-scale hydraulic model of the Seto Inland Sea containing Hiroshima Bay (UESHIMA *et al.*, 1984a, 1984b). While there are other studies of Hiroshima Bay (*e.g.* MUKAI *et al.*, 1980, 1982, 1984, 1985), there is little information concerning *in situ* spatial heterogeneity of this aquatic ecosystem.

MATERIALS AND METHODS

Sampling stations were established to include the major geographical subdivisions of Hiroshima Bay (Figure 1). Surface water samples (0.5 m in depth) were taken with Van Dorn bottles using a boat of the Hiroshima Prefecture in October 1977, June 1978, and March 1979. Salinity and water temperature were determined with a Salinity and Temperature Measuring Bridge (Electronic Switchgear (London) Limited, Type MC-5), calibrated periodically with standard seawater and a mercury thermometer.

Water samples for nutrients and chlorophyll *a* analyses were prefiltered immediately after collection on board through a precombusted 0.8 μm glass fiber filter (Toyo GA 200) and stored in an ice chest during the return to the laboratory. Nutrient concentrations were immediately determined for dissolved inorganic nitrogen (DIN) as ammonium-N (GRASSHOFF and JOHANNSEN, 1972), nitrite-N (BENDSCHNEIDER and ROBINSON, 1952) and nitrate-N (WOOD *et al.*, 1967), and dissolved inorganic phosphorus (DIP) as phosphate-P (MURPHY and RILEY, 1962). The filter residue was used to determine the concentration of chlorophyll *a* by colorimetry after acetone extraction (STRICKLAND and PARSONS, 1968).

Non-prefiltered water samples used for phytoplankton analyses were preserved with neutralized 3% formalin and Lugol's solution immediately after collection for estimation of phytoplankton composition in the laboratory. Because regional differences in the phytoplankton community over the entire bay were detectable at the genus level in the preliminary survey, phytoplankton were identified to genus and enumerated using a binocular microscope (Nikon Model S-Ke) with phase-contrast optics. Counts to at least 10^3 cells were recorded for each sample, because the increase in the value of the Shannon-Weaver diversity index, a measure of the structure of the phytoplankton community, was no longer observed at 10^3 cells or more in the preliminary experiment.

Cluster analysis (based on phytoplankton composition) and multiple discriminant analysis (based on water quality) were performed on a HITAC M-200H computer at Hiroshima University using programs contained in Biomedical Computer Programs (BMDP)(1975) and a Statistical Package for the Social Sciences (SPSS)(NIE *et al.*, 1975), respectively. Cluster analysis (hierarchical classification analysis) in each sampling month was based on phytoplankton genera which appeared during the sampling periods (Tables 1, 2 and 3) and their relative percentage abundance at each station. Similarities in phytoplankton composition between stations were calculated from Euclidean distance.

This distance between clusters was also computed with respect to the centroid of each cluster. On the other hand, multiple discriminant analysis (canonical analysis) using environmental factors was made on the basis of natural logarithmic transformation of physical and eutrophication-related water qualities such as water temperature, salinity, DIN and DIP. In the present study, DIN represents the total sum of the concentrations of ammonia-N, nitrite-N and nitrate-N.

RESULTS

Phytoplankton Community

The phytoplankton genera that occupied Hiroshima Bay on each sampling date are summarized in Tables 1, 2 and 3. The numbers of genera varied considerably during the sampling periods, possibly because of seasonal variations. Of all genera found during each sampling period, *Skeletonema, Chaetoceros, Thalassiosira, Nitzschia, Leptocylindrus, Rhizosolenia,* and flagellates were the most common constituents of the phytoplankton community. As a whole, the phytoplankton composition in October 1977 was relatively diverse and showed a greater variety of genera compared to other sampling months.

Dendrograms produced by cluster analysis, sum-of-squares agglomeration, based on the phytoplankton composition of the major genera for the three groups (or clusters) identified are also indicated in Tables 1 to 3. As seen from the dendrograms in each sampling month, the stations were tightly divided into three distinct groups with differing phytoplankton composition, designated by A, B, and C in the cluster analysis. These three clusters were produced approximately at the 31, 36, and 48.5 levels of similarity based on sum-of-squares distance in October 1977, June 1978, and March 1979, respectively (see Figures 2, 3, and 4).

There were marked differences in phytoplankton composition among the three groups identified by cluster analysis for each sampling month. In October 1977, in Group A, *Skeletonema* was the most abundant genera, comprising 82.5% of the total phytoplankton community. Other genera, however, were sparsely distributed. In Group B, *Skeletonema* remained dominant but its relative composition decreased to 39.9% of phytoplankton present compared with Group A. *Chaetoceros* was the second dominant genera. In Group C, *Skeletonema* de-

Table 1 *Average relative composition of the major genera of phytoplankton (%) for three groups (A, B, and C) identified by cluster analysis in October 1977.*

	Group A	Group B	Group C
Skeletonema	82.5	39.9	13.8
Chaetoceros	4.1	22.5	33.5
Thalassiosira	4.4	1.4	—
Nitzschia	3.9	5.1	3.5
Thalassionema	0.4	1.8	3.8
Asterionella	1.1	6.8	0.8
Leptocylindrus	1.3	2.7	1.2
Rhizosolenia	0.1	0.7	0.4
Bacteriastrum		0.4	0.8
Coscinodiscus	0.3	4.9	18.5
Ditylum	0.1	0.8	1.2
Thalassiothrix	—	0.3	0.6
Eucampia	0.1	—	0.5
Hemiaulus	—	0.2	—
Guinardia	0.3	0.3	2.4
Biddulphia	—	—	0.4
Flagellates	0.2	6.0	6.9
Others	1.2	6.2	11.7

Table 2. *Same as Table 1, but for June 1978.*

	Group A	Group B	Group C
Skeletonema	0.9	11.8	15.1
Chaetoceros	—	1.3	3.1
Thalassiosira	0.3	1.3	0.5
Nitzschia	1.2	2.0	1.5
Leptocylindrus	1.0	16.7	34.7
Rhizosolenia	0.2	5.4	17.6
Cerataulina		1.7	2.1
Flagellates	95.3	57.0	23.6
Others	1.1	2.8	1.8

Table 3. *Same as Table 1, but for March 1979.*

	Group A	Group B	Group C
Skeletonema	75.8	18.0	0.5
Chaetoceros	5.6	36.6	5.8
Thalassiosira	0.4	0.6	0.5
Nitzschia	0.5	2.1	1.0
Thalassionema	0.1>	0.1	—
Leptocylindrus	0.1>	0.1	—
Rhizosolenia	0.1	0.2	0.7
Coscinodiscus	0.1>	0.1	0.8
Ditylum	—	0.1>	—
Eucampia	5.2	11.8	35.0
Hemiaulus	0.1	0.1	0.2
Guinardia	0.1	0.1>	0.5
Corethron		—	0.1>
Biddulphia		—	0.1>
Flagellates	11.9	30.0	54.1
Others	0.2	0.2	0.8

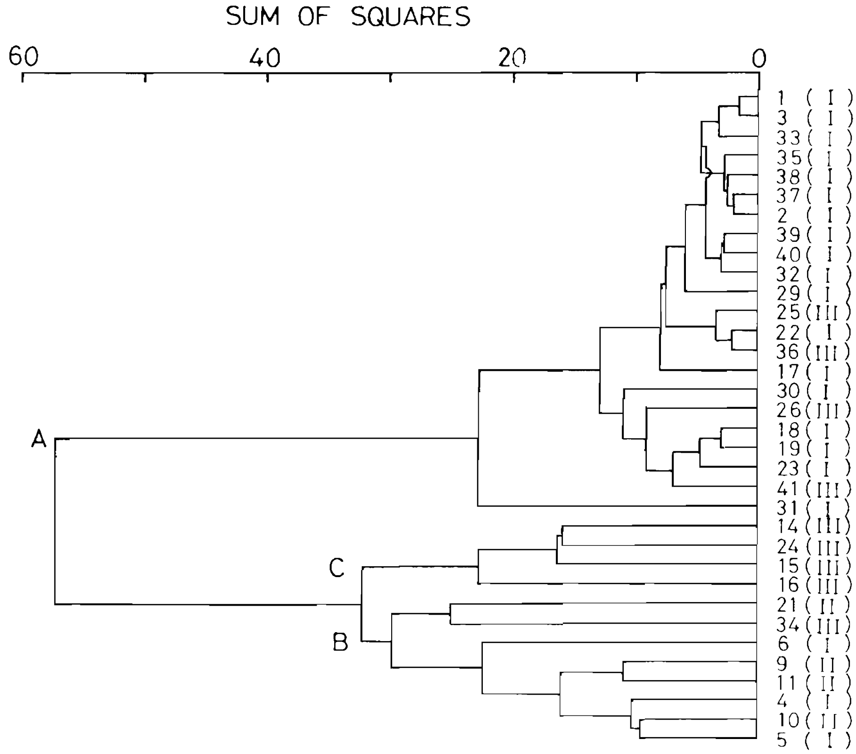

Figure 2 Cluster-analysis dendrogram of phytoplankton composition, based on sum-of-squares distance in October 1977

Table 4 Discriminant analysis of stations based on surface water qualities of Hiroshima Bay in October 1977, June 1978, and March 1979. The data were transformed into the natural logarithm.

	October 1977		June 1978		March 1979	
Discriminant function	1	2	1	2	1	2
Canonical correlation	0.609	0.291	0.846	0.243	0.658	0.162
Percent of separation	86.46	13.54	97.57	2.43	95.57	3.43
	Standardized discriminant function coefficients					
Variables						
Water temperature	0.710	−0.760	−0.567	0.729	−0.120	0.199
Salinity	0.177	0.630	0.850	0.186	1.452	0.330
DIN	0.256	1.237	0.272	−0.551	1.153	1.430
DIP	0.231	−0.715	−0.512	0.160	−0.077	−0.573

creased in its relative composition and *Chaetoceros* spp. were dominant genera. Group B is thus intermediate between Groups A and C (Table 1). In June 1978, in Group A, the most abundant genera consisted of flagellates (95.3% of the total phytoplankton community) whereas other genera were extremely low in relative abundance. In Group B, flagellates were still the most abundant but decreased to 57.0% of phytoplankton present. In contrast, *Leptocylindrus* and *Skeletonema* were relatively abundant, comprising 16.7% and 11.8% of the total phytoplankton community, respectively. In Group C, flagellates were the second abundant genera with *Leptocylindrus* being the first dominant (Table 2). In March 1979, in Group A, *Skeletonema* was dominant (75.8% of phytoplankton present)

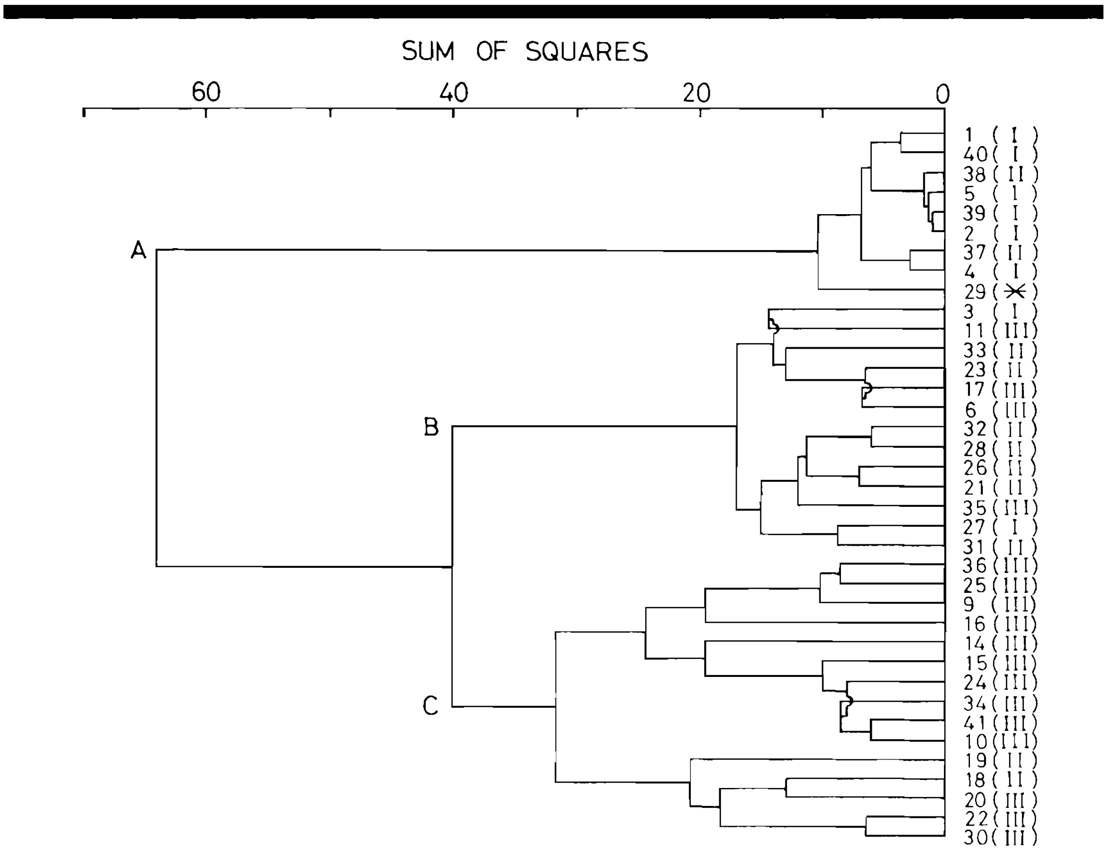

Figure 3. Cluster-analysis dendrogram of phytoplankton composition, based on sum-of-squares distance in June 1978; asterisk denotes the lack of water quality data.

Table 5. *Average water qualities for three groups (I, II, and III) separated by discriminant analysis, together with chlorophyll a concentration.*

	October 1977			June 1978			March 1979		
	Group			Group			Group		
	I	II	III	I	II	III	I	II	III
Water temperature (°C)	22.20	23.86	22.67	22.51	23.10	21.70	12.03	11.78	11.63
Salinity (‰)	31.39	33.05	32.52	20.50	26.50	28.81	30.72	32.80	33.59
DIN (μg at l^{-1})	1.18	1.79	2.26	5.92	1.38	1.32	7.06	1.09	2.75
DIP (μg at l^{-1})	0.37	0.51	0.50	0.90	0.14	0.13	0.24	0.07	0.24
Chlorophyll *a* (μg l^{-1})	10.48	1.70	2.07	73.51	11.47	2.89	6.40	3.69	2.27

while in Group B *Chaetoceros* was dominant (36.6% of the total phytoplankton community) accompanied by a marked decrease in *Skeletonema* (18.0%). In Group C, flagellates were dominant, followed by *Eucampia; Skeletonema* was reduced to 0.5% of phytoplankton present (Table 3).

Surrounding Physical and Chemical Environment

In an effort to clarify the influence of surrounding habitats on phytoplankton composition, water quality (water temperature, salinity, DIN and DIP) was subjected to multiple discriminant analysis based on the three groupings in phytoplankton community composition described in Figures 2 to 4. I assumed that the physical and chemical environment of the study area comprised the three environmentally heterogeneous areas. Consequently, by using the two discriminant functions obtained, each station was discriminated and separated into three groups (with respect to water

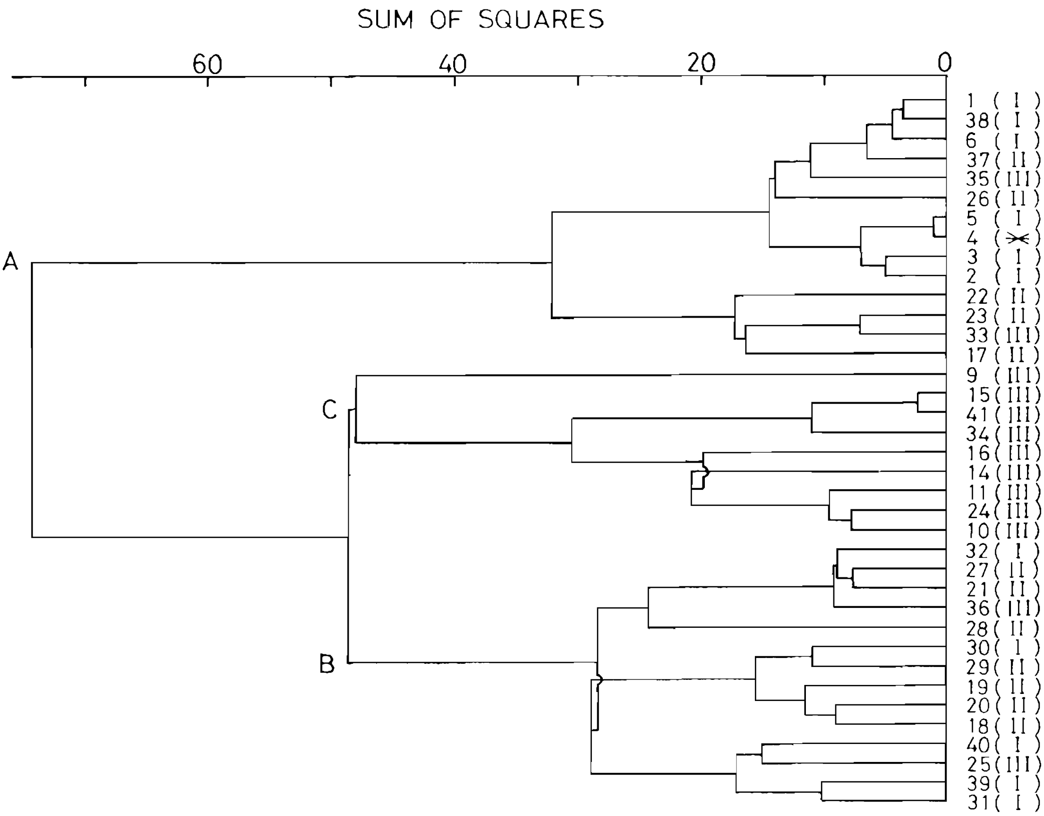

Figure 4. Cluster-analysis dendrogram of phytoplankton composition, based on sum-of-squares distance in March 1979. Asterisk denotes the lack of water quality data.

quality) to produce maximum differences among groups. The results of these operations are summarized in Table 4. The average water qualities for the three groups so separated are given in Table 5 together with chlorophyll *a* concentration. Figure 5 shows these groups projected on the two axes of the discriminant functions (shown in Table 5) so that the stations with similar environmental regimes may form a separate cluster on this graph. The three groups separated are denoted by I, II, and III of multiple discriminant analysis in each sampling month. On the whole, the separation of the stations into the three groups with different water quality environments seems to be relatively distinct in June 1978 and March 1979, whereas in October 1977 the stations appear to be loosely separated. During the sampling period, average water temperature tended to increase in October 1977 and decrease in March 1979 with increasing average salinity. Trends in DIN and DIP, which are associated with eutrophication, were not readily apparent, possibly because their concentrations are subject to marked fluctuation in response to algal growth and discharge of these substances into the bay. In some cases reduced salinity was accompanied by a high concentration of nutrients. The concentrations of chlorophyll *a* decreased with increasing salinity in all sampling months.

Spatial Heterogeneities in Phytoplankton Communities in Relation to Surrounding Environment

The geographical distributions of these three phytoplankton communities and surrounding habitats are shown in Figures 6 and 7, respectively. It is evident from these figures that these three groups were closely related to the geographical position of each station.

Interpretations of spatial heterogeneity in the phytoplankton community are summarized as follows. In October 1977, Group A included stations in

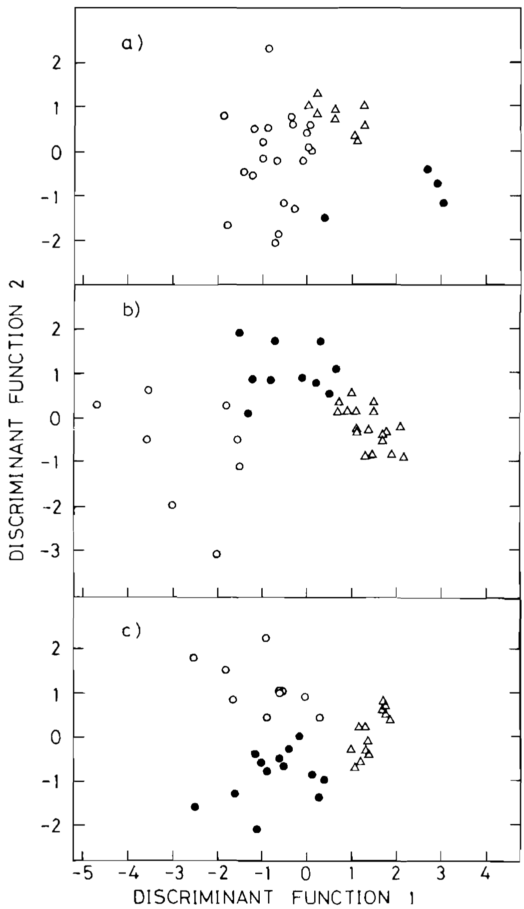

Figure 5. Sampling stations in the into three water-quality groups clustered by similar environmental regimes, for October 1977 (a), June 1978 (b), and March 1979 (c). The open circles, solid cirlces, and trianlges show groups I, II, and III, respectively.

northern and western nearshore areas that were exposed to major river and wastewater inputs. Group B represented many stations that were adjacent to open channels whereas Group C consisted of stations in the central and southern parts of the bay (Figure 6a). In June 1978, Group A was composed of stations in the extreme northern part of the bay that experienced extreme eutrophic conditions. Group B included stations that were contiguous to the northernmost part of the bay, as shown by Group A, and stations in the western part of the bay that were subject to relatively strong influences of river discharge or direct wastewater inputs. Stations represented by Group C extended from the central to southern parts of the bay (Figure 6b). In March 1979, Group A consisted of stations off Hiroshima and Iwakuni. Group B represented nearshore stations along the northern and western coasts of the bay, whereas Group C characterized most stations in the central and southern parts of the bay (Figure 6c).

The three groups were distinguished geographically on the basis of water quality. In October 1977, Group I was composed of stations off Hiroshima and in the western coastal areas. Group II characterized stations near the mouth of the bay. Group III represented stations from the central to southern parts of the bay that were almost free from land-based pollution (Figure 7a). In June 1978, Group I was characterized by stations situated in the innermost region of the bay, *i.e* those which are susceptible to the highest anthropogenic inputs in Hiroshima Bay. Group II represented stations from the northern to to western parts of the bay, whereas Group III included almost all stations in the southern area (Figure 7b). In March 1979, Group I was restricted to stations from the northern part of the bay, whereas Groups II and III tended to occupy stations from the western and central-to-southern parts of the bay, respectively (Figure 7c).

In sum, environmental heterogeneities in Hiroshima Bay were successfully delimited by biological physical and chemical features. Further, as seen from comparison of Figures 6 and 7, spatial patterns in heterogeneity of the phytoplankton community closely resembled those of surrounding environments.

DISCUSSION

Groups I, II, and III, based on multiple discriminant analysis of water quality, are indicated in parentheses in Figures 2 and 4, together with the clustering of the stations into Groups A, B, and C, based on phytoplankton composition.

In October 1977, Group A contained almost all the stations of Group I, except for Stations 25, 26, 36, and 41 of Group III. On the other hand, a large part of Groups B and C contained the stations of Groups II and III, with the exception of Stations 4, 5, and 6 of Group I; Group C was composed of the stations of Group III alone while Group B was dominated by the stations of Group II (Figure 2). In June 1978, Group A was nearly composed of the stations of Group I (6 out of 8 stations), except for Stations 37 and 38 of Group II and Station 29 with an unfortunate lack of water quality data. In Group

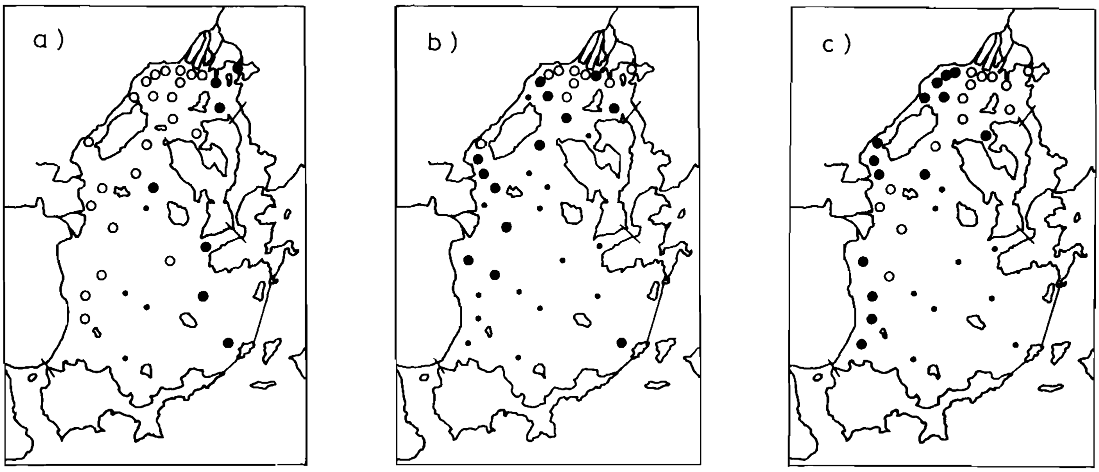

Figure 6. Geographical distribution of the three groups with respect to the phytoplankton communities, represented by the open, solid and small solid circles (Groups A, B, and C, respectively), for October 1977 (a), June 1978 (b), and March 1979 (c).

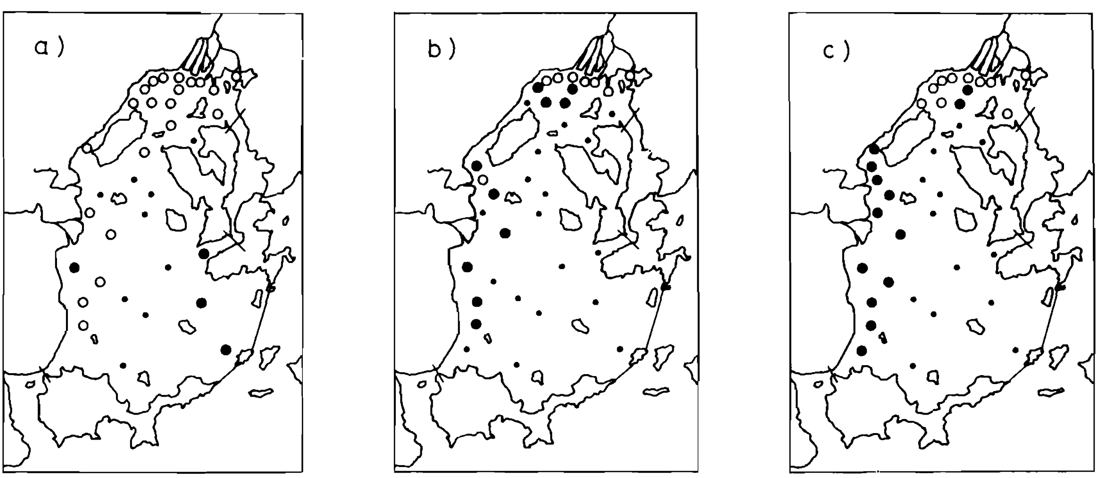

Figure 7 Geographical distributions of the three groups with respect to the surrounding habitats, for October 1977 (a), June 1978 (b), and March 1979 (c). The open, solid and small solid circles show Groups I, II, and III, respectively.

B, the stations of Group II were more abundant than those of Groups I and III (7 out of 13 stations), whereas a large portion of Group C was composed of the stations of Group III (13 out of 15 stations: see Figure 3). In March 1979, most of Group A contained stations of both Groups I and II, while all the stations of Group C were separated into Group III alone with respect to water quality. Group B was dominated by stations of Group II (7 out of 14 stations: see Figure 4).

The above results indicate that an ecological relationship exists between the phytoplankton community and its surrounding habitats. On the other hand, when spatial relationships between the phytoplankton community and surrounding environment is considered, it seems that the distributions of phytoplankton community in the study area approximately parallel major physical and chemical conditions. This relationship may be interpreted as a primary response of the phytoplankton community to changes in environmental conditions, since the phytoplankton community is generally sensitive to fluctuations in the surrounding environment and thus can often be utilized as biological indicators of water pollution (*e.g.* WILLIAMS, 1968; VILLEGAS and GINER, 1973): differences in phytoplankton composition are considered to relect differences in the physical and chemical environment as represented by water quality. Thus, patterns of variability in the constituent genera provide more information about characteristics of the habitat than does variation in a single genus. Further, it seems that these differences in phytoplankton composition are attributable to differences in microhabitats caused by *in situ* environmental heterogeneity within the bay and corresponding habitat preferences of individual phytoplankton species. In addition, as revealed in dendrograms, the number of stations constituting each group (or cluster) with respect to the phytoplankton community appears to fluctuate in response to the magnitude of *in situ* heterogeneity in the surrounding physical and chemical environment that presumably varies with spatial and temporal fluctuations in river discharge, industrial and domestic activities, anthropogenic inputs, hydrographical conditions, *etc.* which are characteristic phenomena in estuarine and coastal environments. Accordingly, these three types of group with respect to the phytoplankton community occupied geographically varying proportions of Hiroshima Bay in each sampling month. For this reason, it was difficult to draw consistent geographical boundaries among the three regions of Hiroshima Bay. The patterns of water mass flow (see Figures 6 and 7) were suggestive of the counterclockwise circulation which was observed by the Maritime Safety Agency of Japan within the central-to-southern parts of the bay (see Figure 13 in MUKAI *et al.*, 1985). These observations were also confirmed in a hydraulic model experiment (UESHIMA *et al.*, 1984a, 1984b). At any rate, it can be presumed that there existed at least three distinct types of water mass based on differences in the phytoplankton community as reflective of differing environmental regimes, occupying the varying proportions of Hiroshima Bay.

As shown in Table 4, it was rather difficult to specify individual effects and relative importance of water quality on the phytoplankton community because the spatial inhomogeneities in the phytoplankton community in estuarine and coastal embayments result from complicated interactions among water qualities considered here and because multiple other factors of unknown relative importance may be involved (TAKAHASHI and FUKAZAWA, 1982; TAKIMOTO *et al.*, 1982, 1983). Finally, it seems that the local physical and chemical environment greatly influences the kinds of phytoplankton that occur, as well as regional differences in phytoplankton composition. These observations could lead to better understanding of the relative significance of regional characteristics in eutrophicating processes Hiroshima Bay (MUKAI *et al.*, 1985).

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□ RESUMEN □

Se han tomado muestras durante un periodo de tres meses de las aguas superficiales de la bahia de Hiroshima, un amplio repliegue costero sujeto a marcada eutrofización. Los aspectos importantes de la heterogeneidad ambiental *in situ* comprenden (1) la comunidad de fitoplancton, que es sensible a las variociones en las condiciones ambientales, y (2) el entorno fisico y chimico como hábitat para la comunidad de fitoplancton. Se han utilizado dos análisis multivariados para obtener relaciones espaciales entre estas dos heterogeneidades ambientales. El análisis de colonias basado en la composición del fitoplancton indicó tres masas distintas de agua que corresponden aproximadamente a las partes norte, oeste y centro-sur de la bahia. Un análisis de discriminante múltiple de la calidad del agua indicó que las diferencias espaciales en la composición del fitoplancton en la bahia eran una primera respuestra de la comunidad fitoplanctónica a las variaciones espaciales *in situ* del entorno fisico y quimico, representado por la calidad del agua.--*Miguel A. Losada, Universidad de Cantabria, Santander, Spain*

□ ZUSAMMENFASSUNG □

Die Oberflächengewässer der Hiroshima-Bucht, die schwer Übernahrung unterliegen, wurden über drei Monat probiert. Wichte Aspekte dieser *in situ* umweltbedingten Verschiedenartigkeit schliessen u.a. (1) die Phytoplanktongemeinde, die empfindlich gegen Änderungen der umweltbedingten Umstände; und (2) die umringende physikalische und chemische Umwelt ein, die für Standort der Gemeinde halten werden. Um die Raumverhältnisse zwischen diese zwei umweltbedingten Verschiedenartigkeiten zu aufklären, wurden zwei Vielvariabelanalysen benutzt. Häufenanalysen, die auf dem Phytoplanktongehalt basiert wurden, zeigten drei verschiedene Wassermassen, die der nördlichen, westlichen und zentral-südlichen Buchtgebiete ungefähr entsprechen. Vielunterschiedungsanalysen der Wasserqualität zeigten, dass die Raumverhältnissen des Phytoplanktongehalts überall in der Bucht eine anfängliche Erwiderung der Phytoplanktongemeinde auf *in situ* Raumverhältnisse der physikalische und chemische Umwelt war, die durch Wasserqualität repräsentiert wird.-*Stephen A. Murdock, CERF, Charlottesville, Virginia, USA*