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La mer, organe de la Sociét franco-japonaise d'océanographie, publie des articles et notes originaux, des articles de synthèse, des analyses d'ouvrages et des informations intéressant les membres de la société. Les sujets traités doivent avoir un rapport direct avec l'océanographie générale, ainsi qu'avec les sciences halieutiques.

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Short-time scale phytoplankton variability and ambient conditions in a highly dynamic marine basin

Wagdy LABIB*

Abstract: The variability of the phytoplankton standing crop, succession and biomass was assessed at surface layer of a fixed sampling station in a highly dynamic marine basin, Mex Bay, West of Alexandria (Egypt). The survey at this station was operated for 50 days between 26 May and 4 September 1992. The bay receives a daily injection of a heavy load of nutrients input from land-based sources. Remarkable physical and chemical variability was observed with the massive development of algal episodes, raising chlorophyll *a* and oxygen content to abnormal values. The causative phytoplankton species of the different blooms achieved their maximum occurrence with different nutrient levels. A phytoplankton bloom is not necessary to accompany or follow a period of enhanced nutrient concentrations. The phytoplankton progressed differently and there was distinct succession in the dominance of the major species. The community structure can be shifted over a few days, another of different species can replace a dense bloom.

Key words : *short-term physical, chemical and phytoplankton variability*

1. Introduction

ROUND (1971) discussed the role of "shock" events associated with changes in daylength, temperature and overturn conditions, in determining species succession and growth. If the actual processes of phytoplankton changes to be understood, short time scale sampling proved to be advisable, instead of weekly or biweekly intervals (WINTER *et al.*, 1975). The timescale variation in phytoplankton abundance, composition and biomass can be circadian (SOURNIA, 1974), seasonal (HARRISON and PLATT, 1980) or vary from a few days to one year (HARRIS, 1980). HARRIS and PICCININ (1980) found that changes in species composition / abundance tend to average environmental variables over short scales. According to CÔTE and PLATT (1983), physical transient events can dramatically alter the species and structural composition of phytoplankton community, conditions for growth and rate of primary production. RICHMOND (1986) reported that phytoplankton require a time from a few hours to several days to adapt a new environmental condition. Studies dealing with the daily changes in plankton population are rather limited (*e.g.* KLEIN and SOURNIA, 1987, SOURNIA *et al.*, 1987 ; ABI-SAAB, 1992).

Mex Bay, west to Alexandria (longitute 29° 50′E and latitude 31° 10′N) has an average width of 3 km, total area of about 20 km^2 and average depth of 10 m (Fig. 1). The bay receives directly from Lake Maryout, through Umum Drain, a daily of $6-11.8 \times 10^6$m^3 of agricultural wastewater (SAID *et al.*, 1991). It is also affected by additional volume of wastewater from industrial outfalls at its western part. The discharge water in to the bay is largely the cause of man-made eutrophication.

The previous investigations on the phytoplankton standing crop in Mex Bay stressed its monthly variations in relation to physicochemical parameters (DORGHAM *et al.*, 1987 ; EL-SHERIF, 1989 ; ABDALLA *et al.* 1992 ; SAMAAN *et al.*, 1992).

The present study represents the first attempt to document the importance of short-time scale sampling to fully describe the phytoplankton variability and ambient envi-

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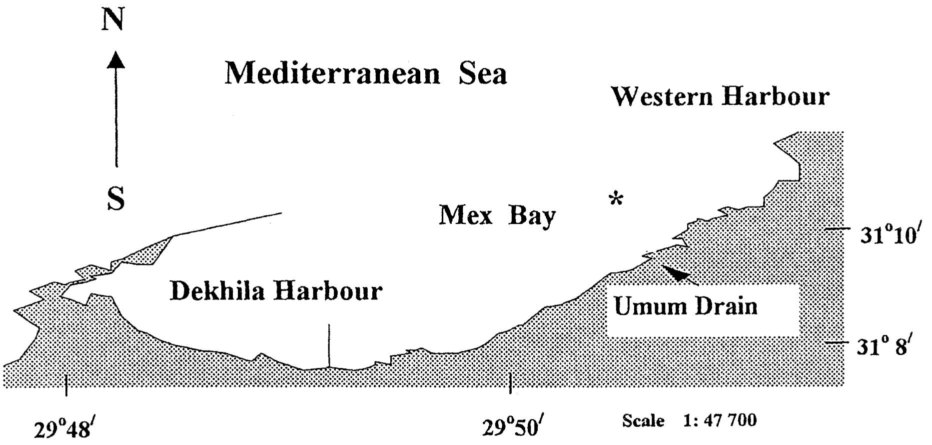

Fig. 1. Study area and sampling station (*).

rommental conditions in a highly dynamic marine basin.

2. Masterials and methods

The sampling station with 5 m depth (Fig. 1) was operated for 50 days between 26 May and 4 September 1992.

The measurements included the determination of the surface water temperature, salinity (refrectometer, S / Mill), oxygen (Winkler method), chlorophyll *a* and nutrient contents, nitrate, nitrite, phosphate and silicate (STRICKLAND and PARSONS, 1972). Water stability calculated on the basis of temperature and salinity data (WILLIAMS, 1962).

The phytoplankton samples were first examined for identification under a research microscope, then preserved by the addition of neutral formalin (4%), and a few drops of Lugol's acid solution and counted (UTERMÖHL, 1958).

The correlation matrix and the multiple-regression stepwise statistical model was computed to understand the relation between the numerical standing crop, chlorophyll *a* (dependent variables) and the measured physico-chemical parameters (independent variables).

3. Results

3-1 Physical conditions

Physical parameters during the period from 26 May to 4 September 1992 are shown in Fig. 2. The most important factors driving the processes that determine the modification of surface temperature and salinity variations seem to be the wide fluctuations of surface heat fluxes (with respect to the limited height of the water column) and the volume of the discharge water (with respect to the whole volume of the basin).

Surface temperature range normally from 21 ℃ with the start to 30 ℃ in late August. Two periods of remarkable temperature increase were recorded during the first week of June and in early July. Generally, temperature shows a tendency to an increase as days went by. Temperature is positively, insignificantly correlated to the numerical standing crop and chlorophyll *a* content ($r=0.157$ and 0.296, respectively). The corresponding multiple-regression equation is :

$$\text{Chlorophyll } a\ (\mu g l^{-1}) = 1.029 + 0.436 \times \text{temperature}\ (R^2 = 0.09).$$

Salinity exhibited wide range of fluctuations. Generally, salinity values are lower than that assumed for the inner boundary of the Mediterranean neritic waters of Alexandria (EL-MAGHRABY and HALIM, 1965 ; SAID *et al.*, 1991). Exceptionally, salinity can be high as 39‰, but values between 209‰ and 339‰ are common. Such high values suggest the lateral advection of the marine water from the open basin. Salinity is insignificantly correlated to the phytoplankton counts and chlorophyll *a* negatively with the latter parameter ($r=0.09$ and

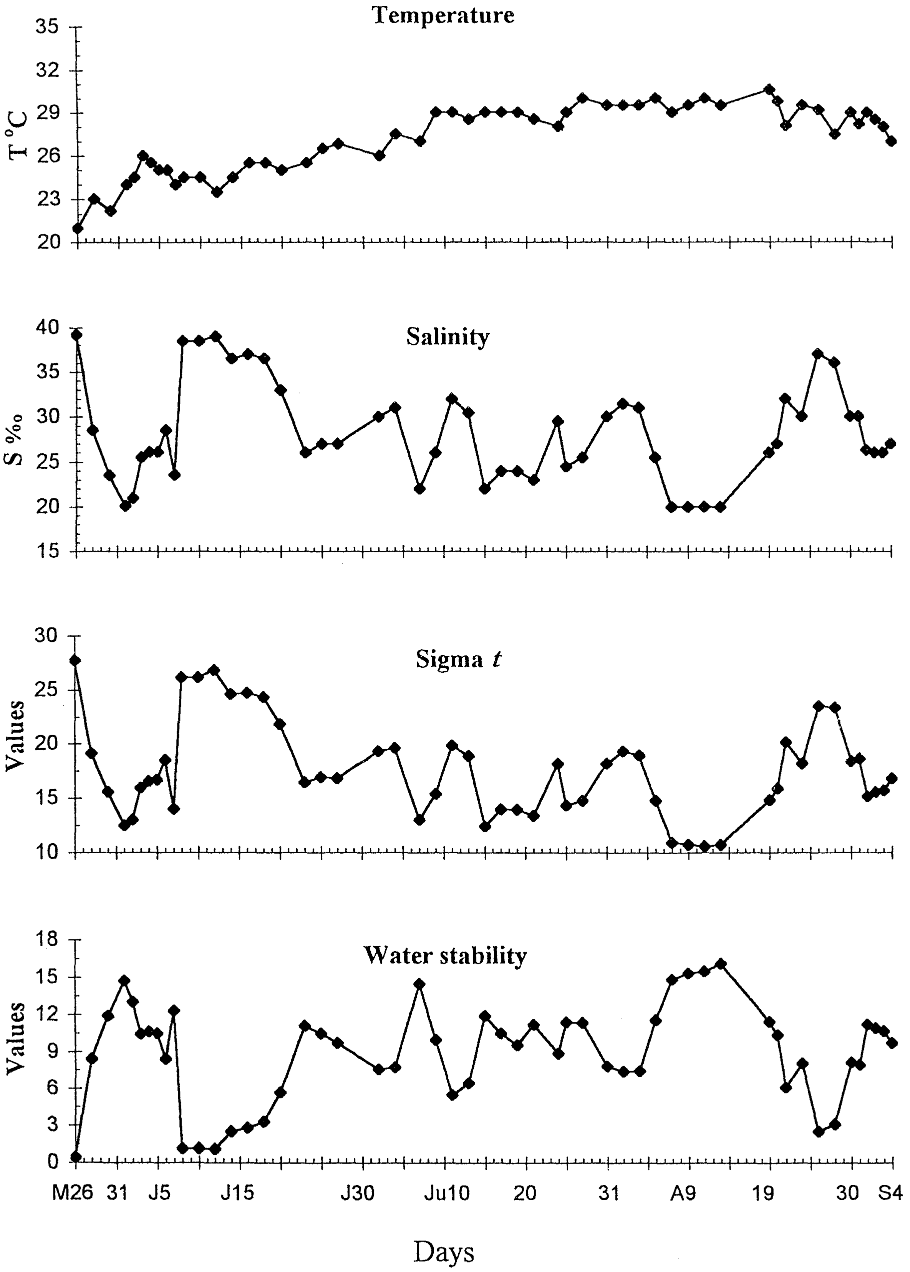

Fig. 2. Physical parameters during the period from 26 May to 4 September, 1992.,

0.10, respectively). The regression equation is :

Chlorophyll *a* ($\mu g\ l^{-1}$) $= 15.527 - 0.111 \times$ salinity ($R^2 = 0.01$).

Water density (Sigma *t*) fluctuations are almost a mirror image of salinity fluctuations rather than temperature (r=0.54 and 0.375, respectively).

Except for higher salinity at times, the water was well stable with maximum (14.84–16.11‰

during 8–14 August), associated with lower salinity over the whole period (20). High values of Sigma-*t* imply small values of water stability and *vice versa*. The permanent stability caused the insignificant correlation with the standing crop and chlorophyll *a* ($r=0.05$ and 0.03, respectively). The corresponding multiple-regression equation is :

$$\text{Chlorophyll } a \ (\mu g\, l^{-1}) = 7.453 + 0.586 \times \text{stability} \ (R^2 = 0.01).$$

However, chlorophyll *a* variations seem depending upon the temperature and stability combination :

$$\text{Chlorophyll } a \ (\mu g\, l^{-1}) = 0.656 + 0.307 \times \text{temperature} + 0.438 \times \text{stability} \ (R^2 = 0.14).$$

3–2 Nutrient conditions

Nutrient concentrations in Mex Bay are mainly governed by their input from land-based sources and the exhaustion by phytoplankton blooms at times (Fig. 3).

Nitrate varied dramatically throughout the whole period. Lower concentrations (1.26–2.8 $\mu mol\, l^{-1}$) were measured during 9–19 June, following a red tide bloom period (*Scrippsiella trochoidea*, the causative organism), and accompanying a minor bloom (predominance of microflagellate species). On the other hand, 3 major nitrate peaks were detected on 26 June (12.78 $\mu mol\, l^{-1}$), 12 August (14.79 $\mu mol\, l^{-1}$), associated with distinct drop in the standing crop (around 0.013×10^6 cell l^{-1}), as well as on 28 August (15.78 $\mu mol\, l^{-1}$), with a moderate phytoplankton increase (0.77×10^6 cell l^{-1}, *Skeletonema costatun*, *Gymnodinium catenatum* and *Nitzschia closterium* dominated).

Nitrite concentrations ranged between 0.35 and 3.9 $\mu mol\, l^{-1}$.

Phosphate concentrations, except for its maximum on 1 September (7 $\mu mol\, l^{-1}$, with the bloom of *G. catenatum*), were always low, exhibiting a narrow range of variations.

Silicate concentrations show a wide range (7.31–64.93 $\mu mol\, l^{-1}$), never fell down limiting the phytoplankton growth. The diatom peaks in July and August occurred with enhanced silicate concentrations.

The high daily injection of the nutrients to the bay leads to continuous replenishment of nutrient elements. Subsequently, insignificant correlation was found between their concentrations and the numerical standing crop and chlorophyll *a* content.

3–3 Phytoplankton variability

The phytoplankton standing crop, chlorophyll *a* and oxygen contents admitted remarkable variation (Fig. 4). The physical and chemical forcing in the bay was favorable to create rich spectra for algal blooms. These blooms resulted in abnormal biomass increase and high surface dissolved oxygen.

The standing crop attained an average of 3.55×10^6 cell l^{-1}, reflecting a clear sign of heavy eutrophication, with a pronounced down shift in the phytoplankton structure. The phytoplankton community was relatively poor (48 species). Diatoms (31 species) contributed an average of 1.67×10^6 cell l^{-1}, 47% to the total, followed by dinoflagelaltes (17 species, 26.2%). The fresh-water forms are numerous, including 9 chlorophycean species (15%, *Ankistrodesmus falcatus*, *Crucigenia quadrata*, *Scenedesmus dimorphus* and *S. quadricauda* were the major species), 6 euglenophycean (8%, mainly, *Euglena acus*, *E. caudata* and *E. granulata*), and 6 cyanophycean (3.8%, *Lyngbya*, *Merismopedia*, *Oscillatoria* and *Spirulina* spp).

The phytoplankton progressed differently during the investigated period. There was distinct succession in the dominance of the major species (Fig. 5 and Table 1).

The dinoflagelate, *Scrippsiella trochoidea*, formed a red tide bloom period between 1–5 June. The centric diatom, *Thalassiosira subtilis*, culminated its peak on 11 June. The dinoflagelate, *Gymnodinium catenatum*, became leading on 8 July. This was followed immediately by the predominance of the pennate diatom, *Nitzchia closterium*. The dominance of diatoms (*Rhizosolenia delicatula*, *Nitzschia closterium* and *Skeletonema costatun*) extended during July – early August. The euglenoid, *Euglena granulata*, shared the dominance to a lesser degree. Again, the dinoflagellates regained their important contribution in late August (*Prorocentrum triestinium*), and in early September (*Gymnodinium catenatum*).

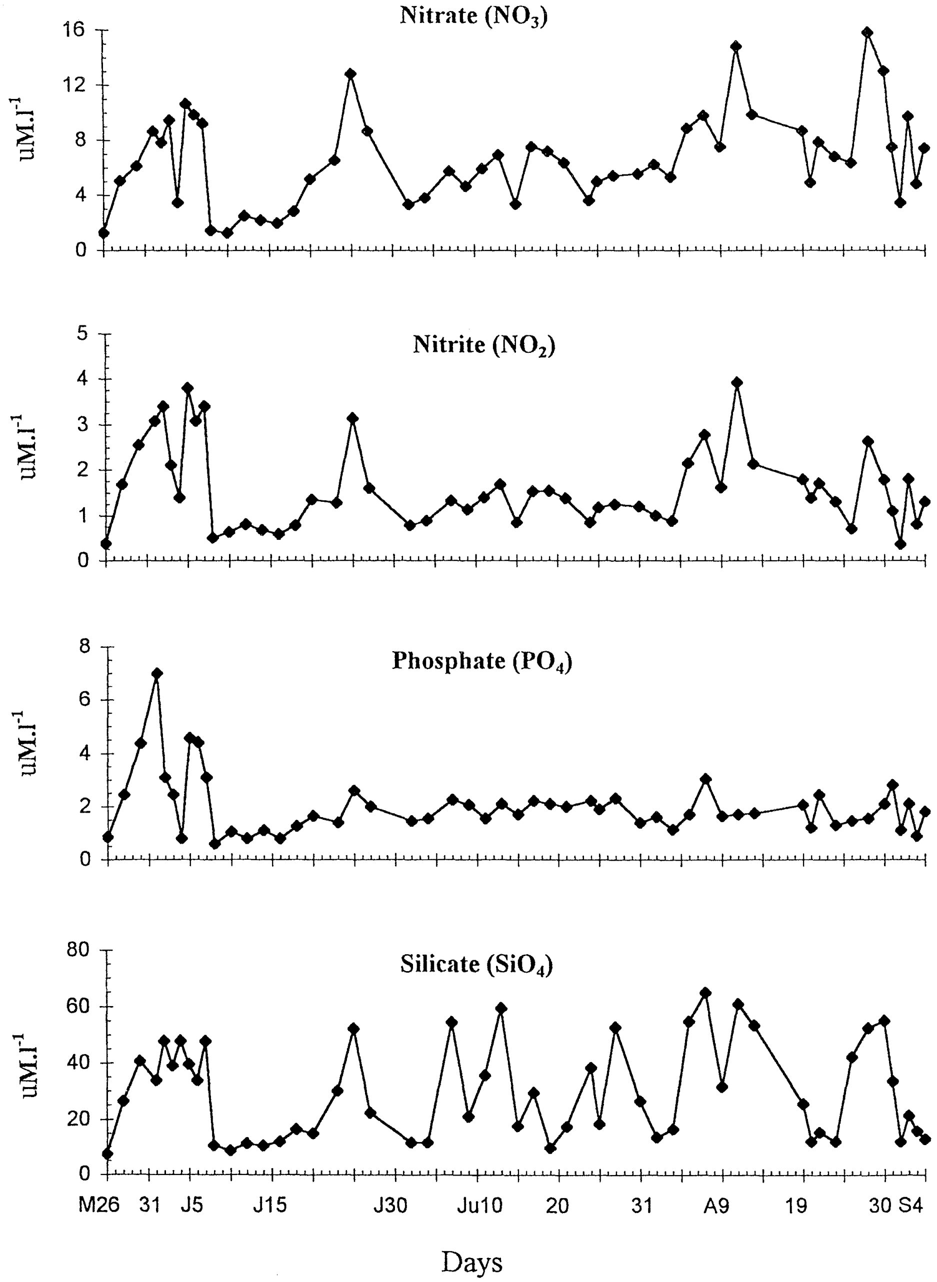

Fig. 3. Chemical parameters during the period from 26 May to 4 September, 1992.

The multiple-regression equations of the major species are given as :

S. trochoidea (cell l^{-1}) $=89.8-11.54\times\mathrm{Temp}$ $-4.22\times\mathrm{S}+3.42\times\mathrm{Sig.t}-1.18\times\mathrm{Sta}$ $+54.83\times\mathrm{NO_3}-99.87\times\mathrm{NO_2}+96.11\times\mathrm{PO_4}$ $+3.48\times\mathrm{SiO_4}$ $(R^2=0.062)$

T. subtilis (Cell l^{-1}) $=42.45-14.9\times\mathrm{Temp}$ $+36.81\times\mathrm{S}-41.92\times\mathrm{Sig.t}-0.05\times\mathrm{Sta}$.

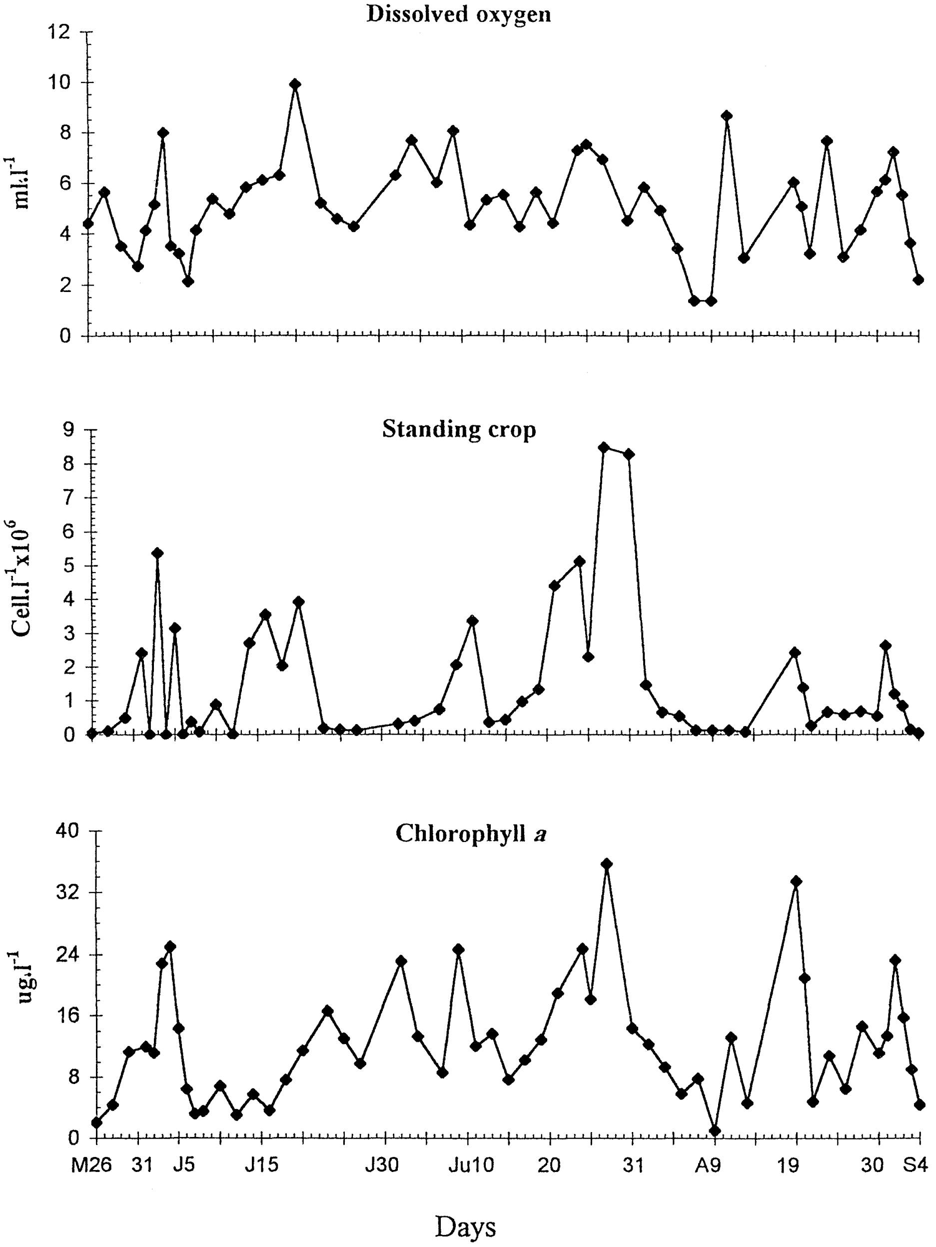

Fig. 4. Dissolved oxygen, standing crop and chlorophyll *a* during the period from 26 May to 4 September, 1992.

$+18.19\times No_3-56.65\times NO_2+42.12\times PO_4$
$+0.23\times SiO_4$ ($R^2=0.113$)

S. costatum (cell l^{-1}) $=148.64-16.31\times$ Temp
$+28.11\times$ S $-31.35\times$ Sig.t $+17.33\times$ Sta.
$-1.37\times NO_3+81.42\times NO_2-42.56\times PO_4$
$-2.11\times SiO_4$ ($R^2=0.14$)

R. delicatula (cell l^{-1}) $=3852.93+10.43\times$ Temp
$-228.65\times$ S $+192.68\times$ Sig.t $-83.6\times$ Sta.
$+17.55\times NO_3-87.69\times NO_2-103.03\times PO_4$
$+0.62\times SiO_4$ ($R^2=0.529$)

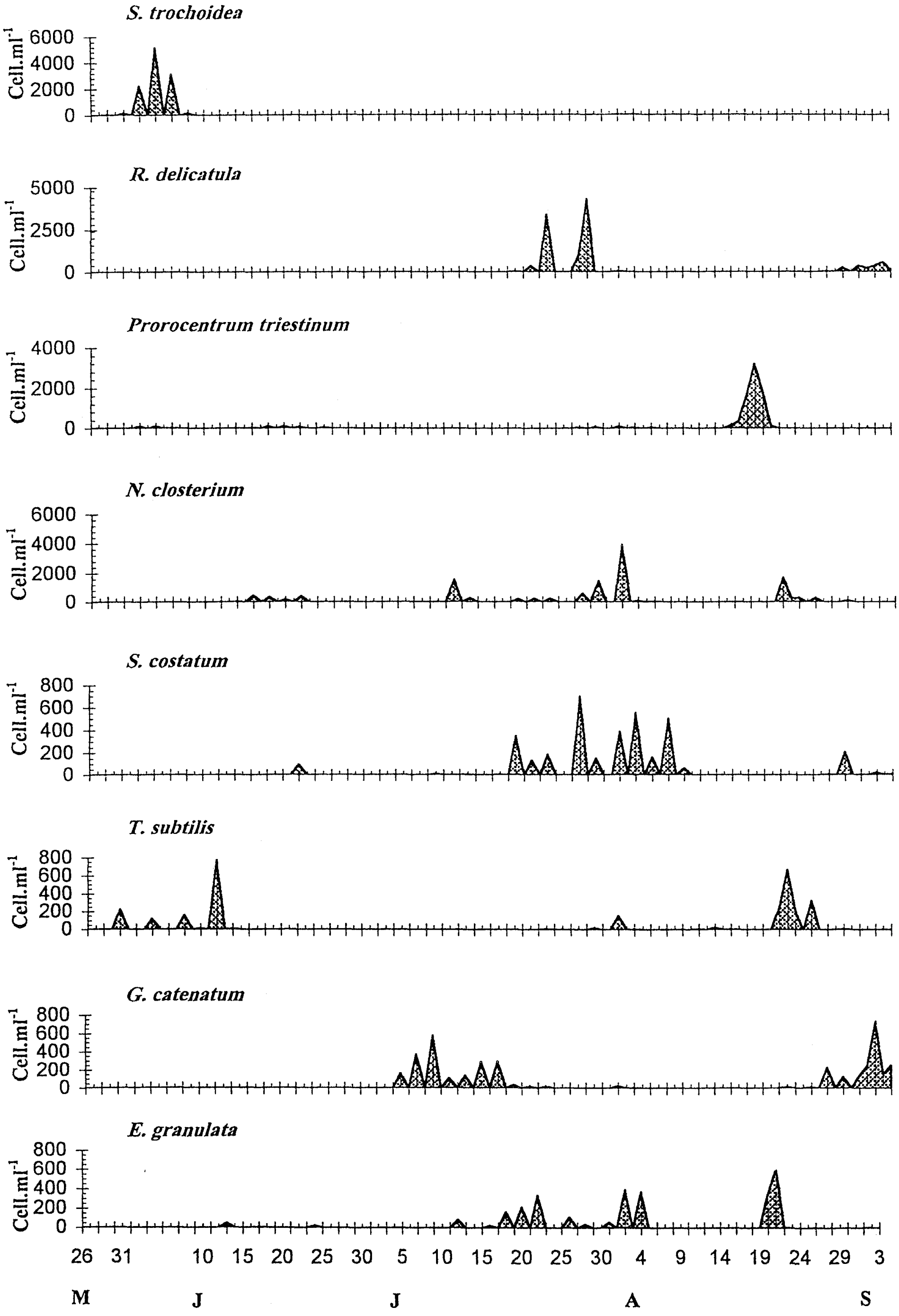

Fig. 5. Dominant phytoplankton species during the period from 26 May to 3 September, 1992.

Table 1. Maximum density of the major species, chlorophyll *a* content, dissolved oxygen and ambient environmental conditions during the investigated period.

Peak day	species	Density (cell $l^{-1} \times 10^6$)	Chl. *a* ($\mu g\ l^{-1}$)	D.O. ($mg\ l^{-1}$)	Temp. (℃)	Sal. (‰)	Sig.t	Stab.	NO_3 ($\mu mol\ l^{-1}$)	NO_2 ($\mu mol\ l^{-1}$)	PO_4 ($\mu mol\ l^{-1}$)	SiO_4 ($\mu mol\ l^{-1}$)
3 June	*S. trochoidea*	5.1	22.83	5.14	26	25.5	15.94	10.38	9.45	2.1	2.45	22.83
11 June	*T. subtilis*	0.76	6.74	5.34	24.6	38	26.14	1.12	1.26	0.63	1.05	8.67
26 July	*S. costatum*	0.70	18.1	7.5	29	24.5	14.32	11.36	4.96	1.18	1.9	18.4
28 July	*R. delicatula*	4.3	35.7	6.9	30	25.5	14.78	11.33	5.38	1.25	2.3	52.7
31 July	*N. closterium*	3.9	14.4	4.5	29.5	30	18.15	7.82	5.52	1.2	1.4	26.6
20 Aug.	*P. triestinum*	3.2	33.4	6	30.6	26	14.83	11.39	8.64	1.78	2.1	25.35
21 Aug.	*E. granulata*	0.61	20.89	5.1	29.8	27	15.84	10.31	4.9	1.38	1.2	11.89
1 Sept.	*G. catenatum*	0.73	23.2	7.2	29	26	15.14	11.21	3.43	0.35	1.1	11.95

$$\begin{aligned}&\textit{N. closterium}\ (\text{cell}\ l^{-1}) = 133.46 + 47.82 \times \text{Temp}\\&\quad - 107.32 \times S + 108.79 \times \text{Sig.t} - 27.76 \times \text{Sta.}\\&\quad + 10.42 \times NO_3 + 89.15 \times NO_2 - 97.06 \times PO_4\\&\quad + 5.89 \times SiO_4\ (R_2 = 0.104)\end{aligned}$$

$$\begin{aligned}&\textit{P. triestinium}\ (\text{cell}\ l^{-1}) = 695 + 2547 \times \text{Temp}\\&\quad - 4009.7 \times S + 3872 \times \text{Sig.t} - 1274.5 \times \text{Sta.}\\&\quad - 4016.7 \times NO_3 + 10644.2 \times No_2 + 862.9 \times PO_4\\&\quad + 286.7 \times SiO_4\ (R^2 = 0.145)\end{aligned}$$

$$\begin{aligned}&\textit{E. granulata}\ (\text{cell.}\ l^{-1}) = 15.78 + 7.04 \times \text{Temp}\\&\quad - 20.52 \times S + 22 \times \text{Sig.t} - 6.59 \times \text{Sta.}\\&\quad + 15.78 \times NO_3 + 21.44 \times NO_2 - 36.6 \times PO_4\\&\quad + 1.3 \times SiO_4\ (R^2 = 0.218)\end{aligned}$$

$$\begin{aligned}&\textit{G. catenatum}\ (\text{cell}\ l^{-1}) = 17.95 + 14.89 \times \text{Temp}\\&\quad - 45.6 \times S + 56.81 \times \text{Sig.t} - 4.23 \times \text{Sta.}\\&\quad - 4.21 \times NO_3 - 16.1 \times NO_2 + 0.445 \times PO_4\\&\quad + 0.65 \times SiO_4\ (R^2 = 0.06)\end{aligned}$$

Generally, chlorophyll *a* runs in parallel with the numerical standing crop ($R^2 = 0.29$). Several peaks were recorded (maximum of 38.9 $\mu g\ l^{-1}$ on 22 July). Deviations are mainly due to species composition.

4. Discussion

The present data shows Mex Bay, subjected to daily input of a huge volume of discharge water, to be characterized by distinct physical, chemical and biological structural properties. The bay is highly eutrophicated with repeated algal outbreaks, causing water discoloration at times. These algal episodes raised chlorophyll *a* content and oxygen to abnormal values.

The daily injection of the nutrients and the permanent stability of the water seem to favor the phytoplankton blooms. However, the data shows that a bloom is not necessary to accompany of follow a period of enhanced nutrient concentrations and even intermediate values are sufficient to trigger a phytoplankton peak.

The phytoplankton species seem to have different nutrientional requirements and it was well documented that the pennate diatoms (*Rhizosolenia delicatula* and *Nitzschia closterium*, the causative species in July and August) require low nutrients to dominate the community (TURPPIN and HARRISON, 1979 ; ISHIZAKA *et al.*, 1983). The species, *Nitzschia frigida* dominated under similar conditions in the Eastern Harbour of Alexandria (LABIB, 1994 a). However, the present dinoflagellates achieved their maximum occurrence under plenty of nutrients. These species were previously recorded red tide forms in the neritic waters of Alexandria (LABIB, 1994, a, b, 1996, 1998 : LABIB and HALIM, 1995).

The success of the pennate *Rhizosolenia delicatula* to grow well under the dinoflagelate bloom of *G. catenatum* agree with other observation in Alexandria waters (LABIB, 1994 a, b).

The community structure can be shifted over a few days. A dense bloom can be replaced by another of different species.

It is concluded that short-time scale sampling in a system of wide fluctuations is advisable to describe its physical, chemical and biological aspects.

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Research on providing habitable environment for bivalves by use of artificial reefs

Hirokazu SUMI* and Akira WADA**

Abstract : In hope of developing technologies for providing habitable environment for bivalves (lamellibranchiata) by utilizing the wave attenuation function of artificial reefs, there is necessity of controlling sea waves and nearshore currents appropriately for the creation of such a favorable environment for shells. In this research, the effect of controlling the wave and nearshore current fields by artificial reefs was studied by hydraulic model tests and numerical calcuations.

In the hydraulic model tests, studies were made on how changes in the distance between dikes (opening width) and the length of dikes would affect flow patterns when installing several artificial reefs on the shore. These flow patterns were classified using the ratio of dike length to openig width. Based on this flow pattern classification, a steady circulation current was formed in nearshore current to allow inner water masses to catch larvae, making it consequently possible to prevent the dissipation of larvae.

In the numerical calculations, the wave and nearshore current fields were simulated with respect to Hamanaka Bay in Hokkaido, where five artificial reefs were installed with the aim of stabilizing the habitat of shells. In the hinterland of the artificial reef, wave heights were found about 30% less than those without artificial reef. Flow velocities wave weaker than those without artificial reef, thus making it possible to prolong the retention time of larvae and promote their implantation. Flow velocities at each calculation points were lower than the critical migration velocities of shells, enabling the artificial reef to prevent shells from being washed up and proving the effectiveness of such mounds in stabilizing the habitat.

Key words : *artificial reef, bivalve, hydraulic model test, numerical calculation*

1. Introduction

As one of measures to promote the harmonius coexistence of coastal-zone development and environmental conservation, the construction of coastal structures leading to the increased propagation of biological resources is sought for, and at the same time expectations are placed on the development of technologies to provide bivalves with an ideal habitable environment by utilizing the wave attenuation or sedimentation function of submerged mounds or artificial reefs (submerged breakwaters with wide crown).

In addition to the conventional coastal protection, the functions desired of these technologies include (1) promoting the implantation (agglomeration function) of bivalves' planktonic larvae and (2) securing a tranquil sea area and sandy-silt zone where postimplantation bivalves can live (habitat protection function). The artificial reef causes wave breaking on the crest and makes waves in the hinterland of the dike tranquil, so that the orbital velocity in the vicinity of the sea bottom due to a wave motion can be reduced and the overturn or exposure of shells can be prevented. Moreover, as the nearshore current is controllable, the diffusion prevention of planktonic larvae due to the current and the promotion of their implantation to sediments can be expected. It will be advantageous if the installation of such a artificial reef can

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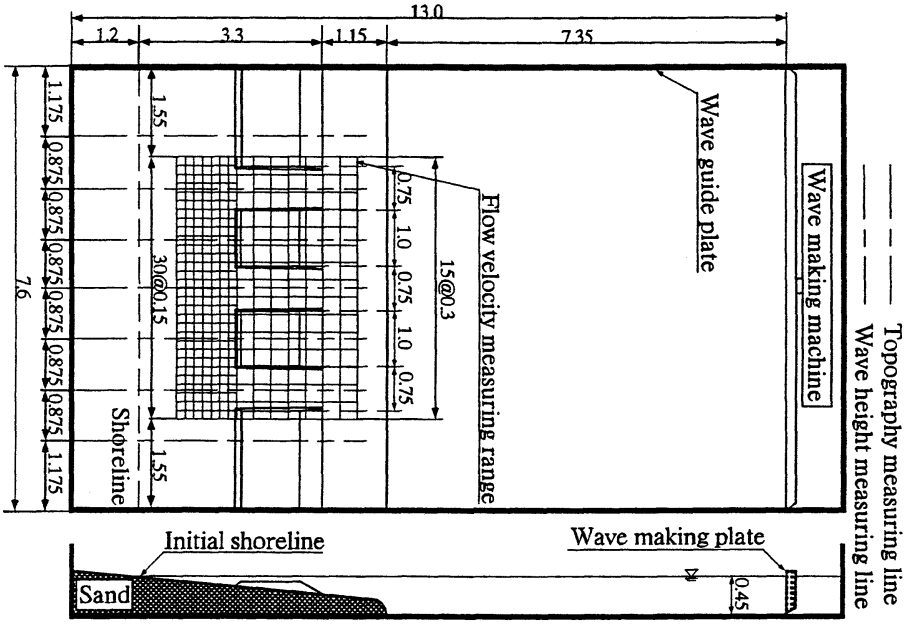


Fig. 1 Ourline of horizontal water tank (unit : m)

consequently stabilize the habitat suitable for the growth of bivalves.

In this research, therefore, taking into consideration that the creation of a favorable habitat for bivalves requires appropriate control of sea waves, nearshore current and littoral drift, which are the principal elements dominating the habitat environment, studies are made on the hydraulic characteristics that can be controlled by installing the artificial reef on the coast, from both aspects of hydraulic test and numerical simulation. Firstly, a movable bed test is conducted to obtain basic information on what kind of effect the changes in the length of a dike and the length of an opening will have on the flow pattern of a nearshore current or the formation of a circulation current and the stabilization of a shore when several artificial reefs are installed on the coast. Next, a numerical simulation is carried out with respect to Hamanaka Bay in Hokkaido where five submerged mounds are installed on the sandy beach, in order to study the effect of control in a wave field and nearshore current field by a group of submerged mounds.

2. Plane movable bed test on flow and littoral drift around the artificial reef

When installing several artificial reefs on the coast, a general practice is to install an opening between dike bodies. At this time, changing the dike length of the artificial reef and the length of the opening generates a characteristic nearshore current owing to changes in the height of transmitted waves which pass through above the dike and the opening, thereby causing the coastal topography to change, as is known by various kinds of past research (for example, UDA and KOMATA, 1987). However, it is hard to say that sufficient explanations have been made on hydraulic characteristics concerning the relation between flow patterns and shore changes when the dike length and opening width are changed. In this chapter, therefore, studies are carried out to determine what kind of effect the dike length and opening width will have on the flow pattern, the formation of a circulation current and the stability of a shore when several artificial reefs are installed.

2.1. Test method

The test was conducted using a horizontal

Table 1. Test cases and flow patterns

Case No.	Dike length Lr(m)	Opening width W (m)	Offshore distance Y (m)	Flow pattern	Illustration
1	2.0	0.3	1.8	On-offshore current	Fig.3 (a)
2	2.0	0.8	1.8	Stable circulation current	
3	1.0	0.22	1.8	Unstable circulation current	Fig.3 (b)
4	1.0	0.8	1.8	Stable circulation current	Fig.3 (c)
5	1.0	1.3	1.8	Stable circulation current	

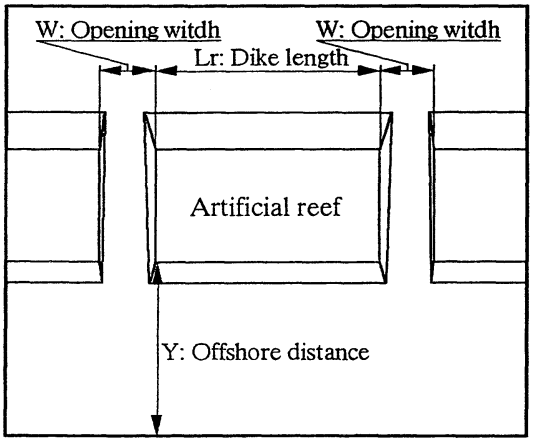


Fig. 2 Plane parameters of artificial reef.

wave-making tank (measuring 13.0 m long, 7.6 m deep and 0.5 m high) (see Fig. 1). Froude similitude was used as a law of similarity. The scale of a non-distorted model is 1/50, and the shore model is an artificial reef model installed as a rubble mound using silica sand of $d_m=0.19$ mm in median grain size with crushed stone weighing 3 to 4 g placed on the initial gradient of $i=1/15$. The dike has the following section parameters : $s=1/3$ in inclination of slope, $B=1.0$ m in crown width, $d=14.0$ cm in body height, $R=6.0$ m in submerged depth of crown. Plane parameters consist of dike length Lr, opening width W and offshore distance Y as shown in Fig. 2, and these were combined as shown in Table 1. As working wave conditions, $H_I=6.0$ m in incident wave height, $T=1.13$ s in period and 0° in wave direction (perpendicular to the shoreline) were applied for 5 hours.

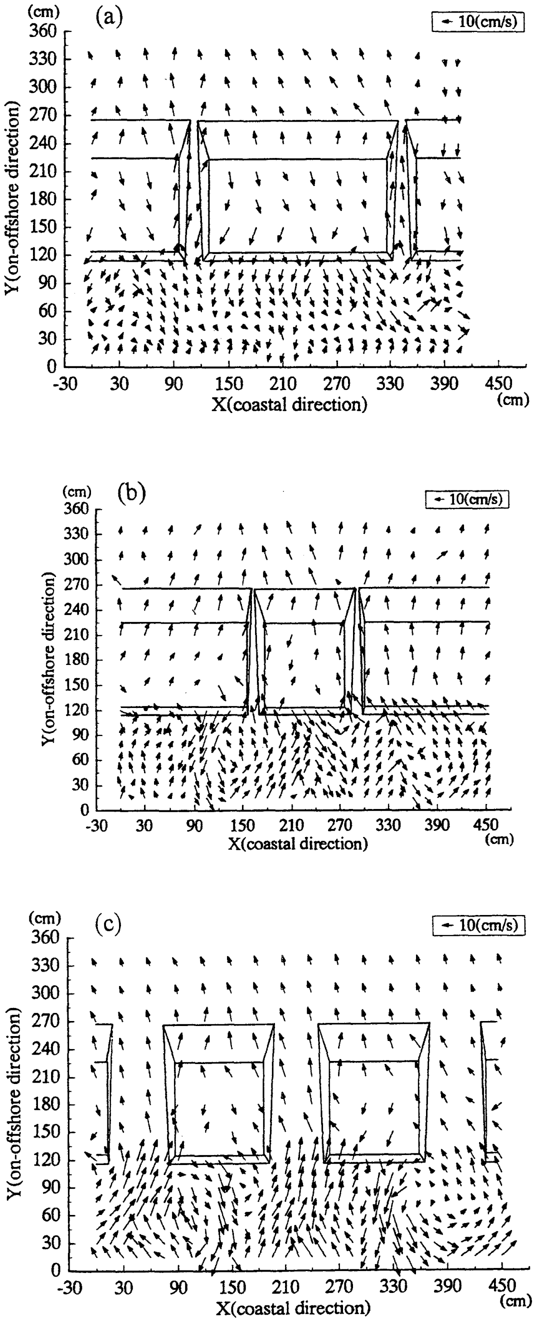


Fig. 3 Nearshore current aronund the artificial reef, (a) dike length : 2.0m, opening widht: 0.3 m, Case 1, (d) dike length: 1.0m, openingwidht: 0.22m, Case 3 and (c) dike length: 1.0m, openig width: 0.75m, Case 4.

The flow pattern of a nearshore current, the topography of a shore and the distribution of wave heights were measured. To determine the flow pattern of the nearshore current, as shown in Fig. 1, the velocity of flow was measured using an electromagnetic current meter at about 350 points around the artificial reef in the square grid divided at intervals of 30 cm from the offshore side to the toe of slope and at intervals of 15 cm at the back of the dike. At the same time, observations were made of flow patterns by means of floats and recorded with an 8 mm video camera from top of the water tank. The topography of the shore and the distribution of wave heights were measured at intervals of 20 cm in the on-offshore direction by installing a measuring line in the direction perpendicular to the shoreline against the combination of each test plane.

2.2. Test results and considerations

2.2.1. Nearshore current around the artificial reef

To carry out studies on the nearshore current around the artificial reef, an attempt here is made to identify the correlation between each test case concerning flow patterns which vary according to the setting of dike length and opening width, Figures 3(a), (b) and (c) indicate respectively the velocity distributions of (1) on-offshore current (Case 1), (2) unstable circulation current (Case 3) and (3) stable circulation current in the hinterland of the dike (Case 4).

In Cases 1 and 2 where the opening width was changes as $W=0.3$ m and 0.75 m with the same dike length ($Lr=2.0$ m), the current was flowing in the offshore direction in both the offshore side of the dike and the opening. In the hinterland, in Case 1 with a narrow opening width, the current flowing in the on-offshore direction was recognized, while in Case 2 with a large opening width two circulation currents were found generated. In Cases 3, 4 and 5 where the opening width was changed as $W=0.22$ m, 0.75 m and 1.25 m with the same dike length ($Lr=1.0$ m), the current flowing in the offshore direction was generated in the offshore side of the dike and the opening. In the hinterland, in Case 3 with a narrow opening, the onshore current and rip current were irregularly recognized and an indistinct circulation current was found generated, while in Case 4 whose opening width is between Case 3 and Case 5, one circulation current was found formed at the back of the dike. Also, in Case 5 with the largest opening width, two circulation currents were found generated.

Thus, it is evident that if the dike length is constant, the larger the opening width is the more likely the circulation current is generated. It is also evident that in the offshore side of the dike and the opening, the flow pattern is in the offshore direction irrespective of dike length and opening width, while in the onshore side of the dike the flow pattern of a nearshore current varies with the setting of dike length and opening width. In addition, to promote the implantation of planktonic larvae and the reduction of diffusion through the use of the artificial reef, the generation of a stable circulation current in the habitat is desired and at the same time, it is necessary to establish a criterion for setting the dike length and opening width.

Figure 4 shows the relation between Lr/W and Lr/Y, in comparison with the past research results. The marks (○,∅,▽,□) indicate the test results obtained by Uda *et al.* (1987), while those shown in black are the test results obtained in this research. The case in which the circulation current is generated and the case in which the on-offshore current is predominant indicate results almost similar to the past research, and it can be considered that the flow pattern around the artificial reef is governed by Lr and W. Accordingly, from the test results obtained in this research and the research results obtained by Uda *et al.* (1987), it can be assumed that the flow-pattern in the hinterland of the dike consists of three conditions, i. e., $0<Lr/W\leq 4$ as a domain in which a stable circulation current is generated, $4<Lr/W\leq 6$ as a domain in which an unstable circulation current is generated, and $6<Lr/W$ as a domain in which no circulation curent is generated. Using this flow-pattern, a steady circulation current is allowed to be formed in the nearshore current, with planktonic larvae trapped in its inner water mass so that the dissipation of

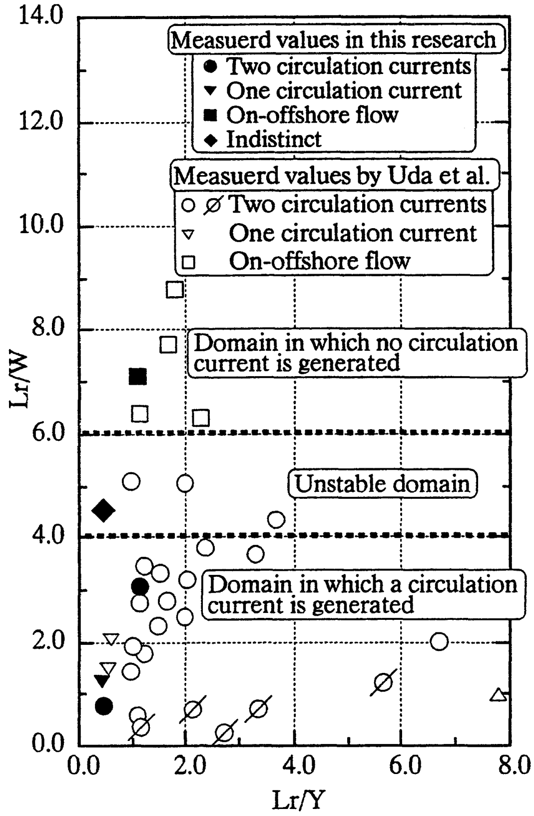


Fig. 4 Flow pattern occurrence classification.

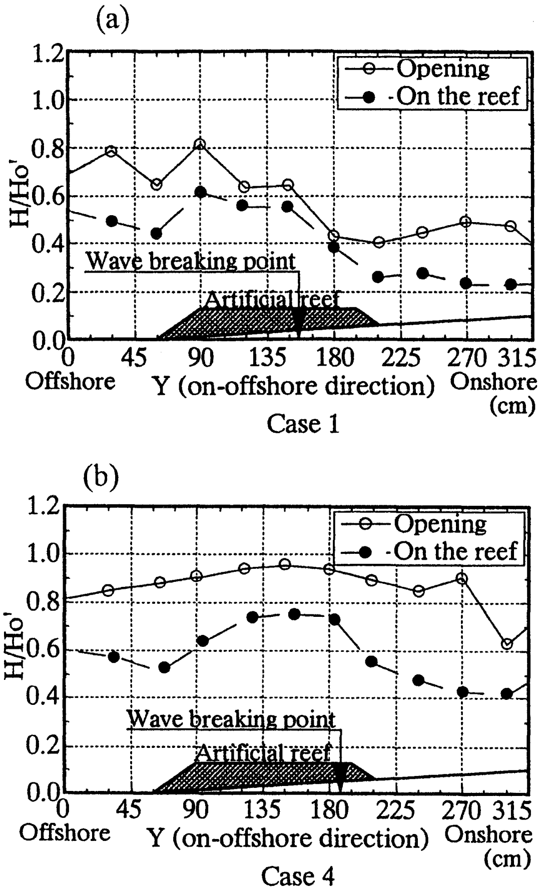


Fig. 5 Wave height distribution in the on-offshore direction of artificial reef, (a) dike length: 2.0m, opening width: 0.3m and (b) dike length: 1.0m, opening width: 0.75m.

larvae can be prevented.

2.2.2. Wave height distribution

Figure 5 shows the comparison of changes in wave height between the case where the on-offshore current is generated and the case where the circulation current is generated. The longitudinal axis in the figure indicates the plot of H/Ho′ in the on-offshore direction. H is wave height obtained from the test, Ho' is wave heigth due to offshore diffraction or refraction. Figure 5(a) shows changes in wave height in the case where no circulation current is generated, while Figure 5(b) shows those in the case where one circulation current is generated in the hinterland. The wave height on the reef in the hinterland of the dike is showing an attenuation of about 50% in Fig. 5(a) and about 40% in Fig. 5(b). On the other hand, the wave height in the opening is attenuating in Fig. 5(a), while in Fig. 5(b) the incident wave reaches the onshore side without undergoing attenuation and the wave-height difference on the reef and in the opening is increasing as compared with Fig. 5(a). Thus, assuming that the difference of wave height on the reef and in the opening is related to the generation of the circulation current, Fugure 6 shows the relation between W/Lr and nondimensional wave-height difference (Hm-Ht)/Ho′ obtained by making the difference between wave height Hm in the opening and transmitted wave height Ht in the hinterland dimensionless by Ho′. From this fugure, it is evident that the larger W/Lr and the smaller Lr/Y the larger becomes the difference in wave height on the dike and in the opening and the more likely the circulation current is generated.

2.2.3. Topographic change

It can be considered that the phenomenon of littoral drift around the artificial reef is related to a nearshore current. To grasp the migration of sand caused by the nearshore current, therefore, the horizontal distribution of coastal topographic changes from the initial slope were obtained from the coastal topography 5 hours after starting wave generation, as shown in Figs.7 and 8. Although similarity laws were not sufficiently established in the test on littoral drift, topographic changes around structures due to currents were studied qualitatively and the Froude similitude was followed because of placing emphasis on the fluid motion.

Figure 7 shows topographic changes without artificial reef. From the neighborhood of the shoreline up to Y=125 mm, sand erosion takes place and a trough is generated. Up to Y=150 to 250cm, bar-type seabed topography with sand deposition and growth of a longshore bar is recognized.

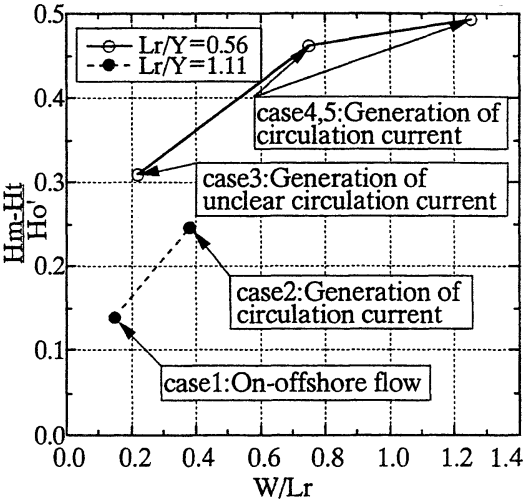


Fig. 6 Relation between wave height difference and generation of circulation current.

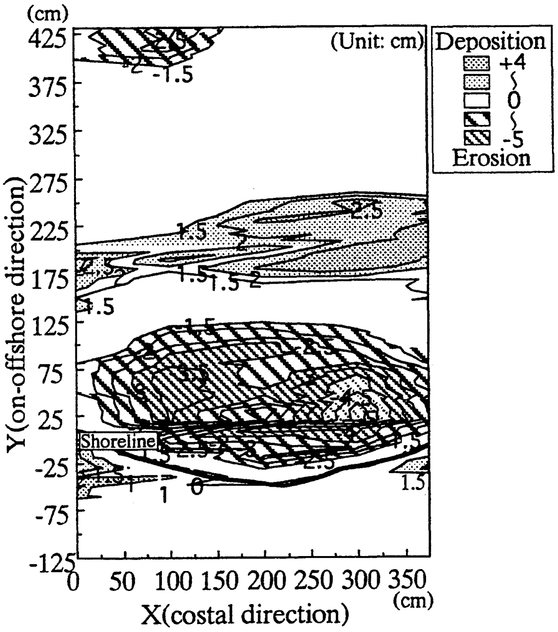
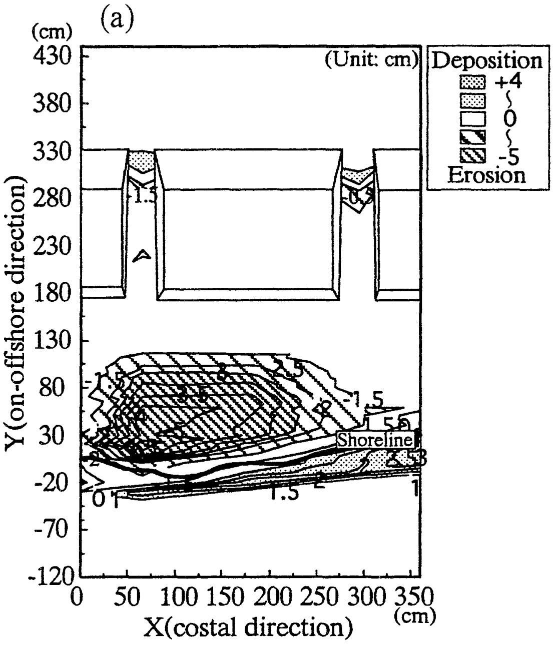
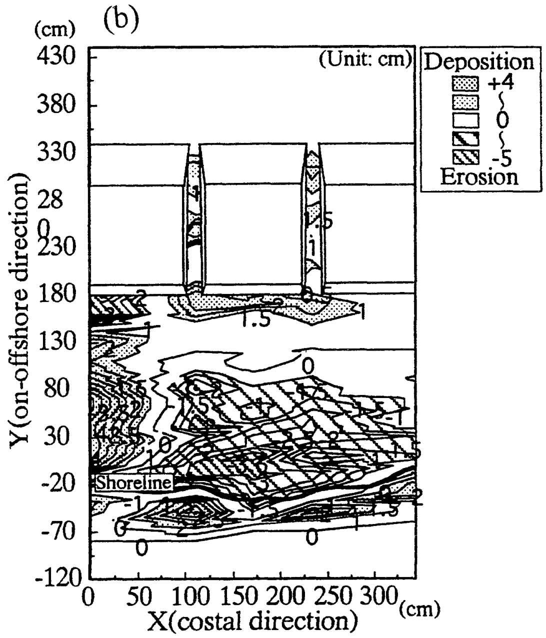


Fig. 7 Topographical changes without artificial reef.

Figure 8(a) shows topographic changes in Case 1 where a current in the on-offshore direction is generated. In the hinterland, an onoffshore sediment movement occurs due to the onshore current and rip current generated at the back of the dike, causing erosion from the shoreline up to Y=100 cm. The sand deposition is found on the foreshore. Fugure 8(b) shows topographic changes in Case 3 where an unstable current is generated. Up to X=0 to 50 cm, sand deposition is recognized from the back of the dike to the shoreline, while sand erosion is recognized up to X=500 to 350 cm. It can be considered that this complicated beach configuration is related to the generation of an irregular onshore current and rip current at the back of the dike. Also, eroded sand is deposited near the toe of slope and on the foreshore. Figure 8(c) shows topographic changes in Case 4 where a stable circulation current is generated. Sedimentation is recognized near the toe of slope and on the foreshore, and erosion is found from Y=80 cm to the shoreline. Considering the balance of sand, it seems that sedimentation near the toe of slope was transported owing to the circulation current, indicating that the dike prevented the runoff of sand to the offing. The shoreline was advancing about 40 cm greater than that without artificial reef, the growth of steps was recognized and





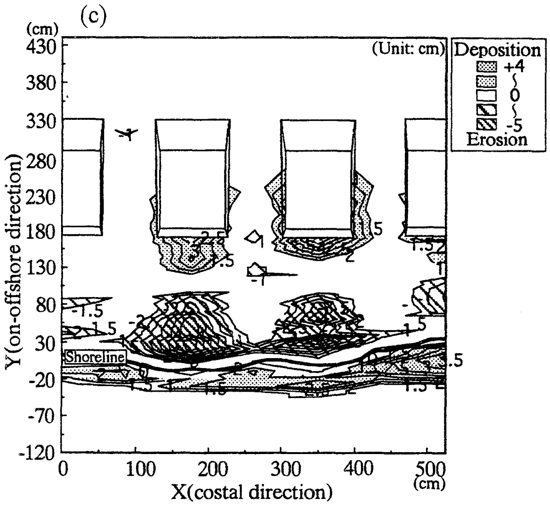


Fig. 8 Topographical changes around the artificial reef, (a) dike length: 2.0m, opening width: 0.3m, Case 1, (b) dike length: 1.0m, opening width: 0.22m, Case 3 and (c) dike length: 1.0m, oprning width: 0.75m, Case 4.

the foreshore was found extended, thus conspicuously indicating the effect of littoral drift control by the artificial reef.

The stabilization of sediments becomes an important problem when we try to reduce wear due to the overturn and exposure of bivalves. Topographic changes in the case where artificial reefs are installed on the beach vary with the flow pattern of a nearshore current. In the case where the on-offshore flow is predominant, sand deposition takes place on the foreshore only. In the case where a circulation current is generated, sand deposition takes place near the toe of slope and on the foreshore. Also, the shoreline advances greater than that without artificial reef, and the inshore erosion zone becomes smaller. Thus, the artificial reef minimizes topographic changes in the hinterland and promotes the stabilization of sediments, thereby possibly contributing to reducing the on-the-sand exposure and swash of shellfish larvae and adult shells.

3. Numerical simulations on wave field and nearshore-current field

In Hamanaka Bay which is located in the eastern part of Hokkaido as shown in Fig. 9, five artificial reefs are installed along the sand coast for the purpose of stabilizing the habitat of bivalves. The mouth of Hamanaka Bay is opening eastward and has a width of about 6

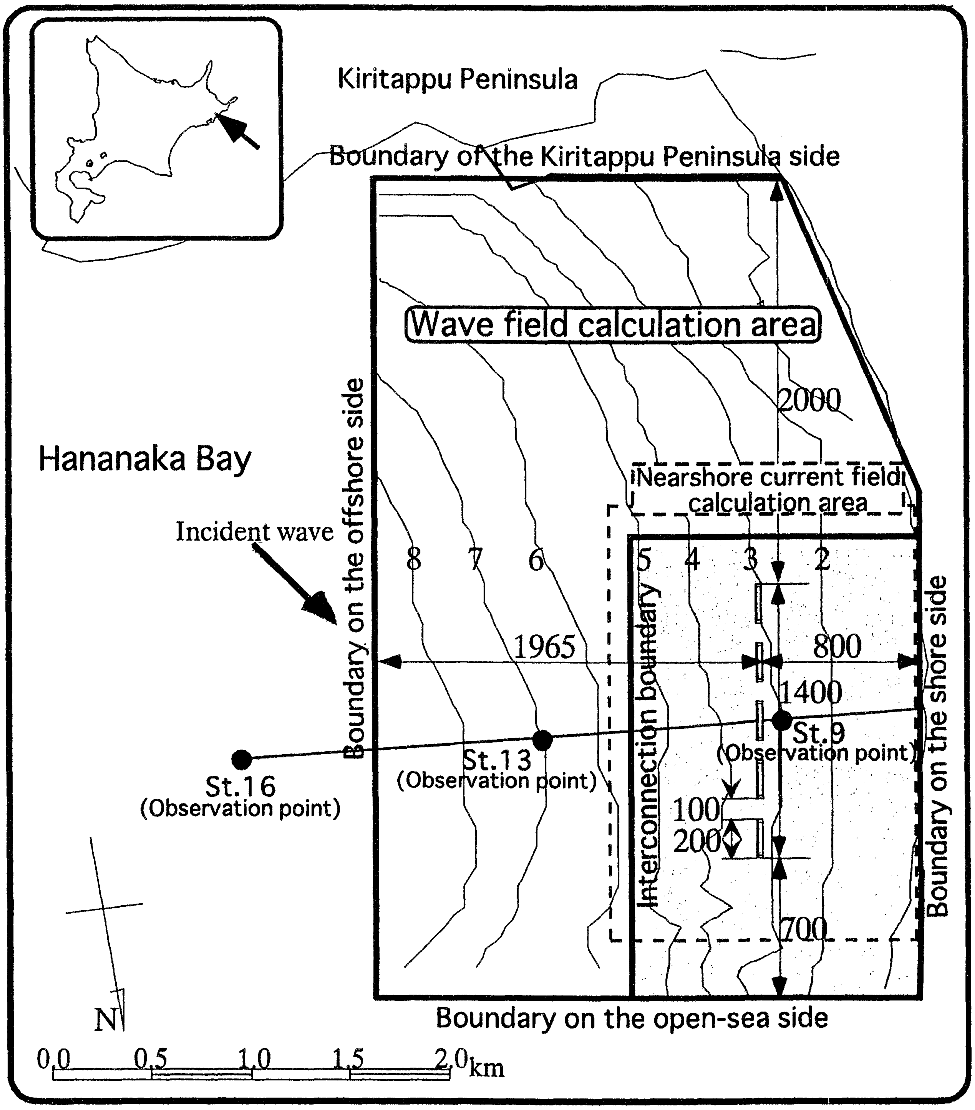


Fig. 9 Study area(unit: m).

km. The depth of water in the bay is less than 20 m, with a gentle gradient (1/280). According to Mimura et al. (1996), bivalves are the major fishery resources in this bay, though the number of bivalves living in the bay is on the decrease and there is concern about the upkeep of these resources.

To develop technologies relating to the creation of bivalve fish grounds, it is pointed out that sea waves and nearshore currents are important elements in the formation of a habitat (Itosu, 1985). In the field survey carried out in the summer of 1996, however, wave and current observations were conducted only at three points in the bay, which was insufficient to grasp in detail the condition of waves and flows in the vicinity of artificial reefs. In this report, therefore, a description is made on the numerical simulations which are conducted on the wave field and nearshore current field around the artificial reefs, and comparisons are made with on-site observed values, to examine the effect of controlling the sea waves and nearshore current by a group of artificial reefs.

3.1. Numerical simulation on the wave field

The calculation of a plane wave field may be broadly classified into two methods, depending on how waves are dealt with. That is to say, one method deals with waves as the equation of energy and another method deals with waves as the equation of motion (HONMA and HORIKAWA, 1985). A typical wave model of the former is the energy balance equation (hereinafter called EBE), while that of the latter is the time-dependent mild slope equation (TDMSE). EBE is a wave model which can simultaneously solve the refraction of multidirection random waves and the wave shoaling. Howaver, the field of progressive waves whose single direction can be defined at each calculation point is a precondition for this model, thereby making it difficult to apply the model to the analysis of a field in which waves are superimposed owing to reflection or diffraction. TDMSE is a model that can comprehensively evaluate the principal deformations of waves in the shallow sea, i. e., shoaling, refraction, diffraction, reflection and breaking, though its handling is limited to regular waves.

The wave models have their own characteristics, and it is therefore necessary to determine the scope of application appropriately according to purposes. For example, in the case that (1) offshore waves suffer only refraction or shoaling owing to the effect of seabottom topography or (2) waves suffer attenuation in height simultaneously owing to diffraction, reflection or breaking caused by the effect of coastal structures built near the shoreline in the shallow sea, it is necessary to use a wave model which can appropriately evaluate the deformation of waves in the respective sea areas.

Then, to estimate the plane wave field around the artificial reefs built in the coastal area of Hamanaka Bay, interconnection calculations are carried out on the two wave models, EBE and TDMSE. That is to say, in the offing where waves are not affected by structures, EBE is used, while in the sea area where waves are affected by structures, TDMSE is used to estimate the wave field in the sea area concerned.

3.2. Basic equations

EBE, to which the wave-breaking attenuation term is added, is given by equation (1).

$$\frac{\partial}{\partial x}(SC_g\cos\theta)+\frac{\partial}{\partial y}(SC_g\sin\theta)+\frac{\partial}{\partial\theta}\left\{S\frac{C_g}{C}(\sin\theta\frac{\partial C}{\partial x}-\cos\theta\frac{\partial C}{\partial x})\right\}=-\varepsilon_b S \tag{1}$$

Where, S : Direction spectrum, C_g : Group velocity, C : Wave velocity, θ : Wave direction, ε_b : Wave-breaking attenuation term.
Also, TDMSE, to which the wave-breaking attenuation term is added, is given by equations (2a, 2b) and equation (3).

$$\frac{\partial Q_x}{\partial x}+C^2\frac{\partial\zeta}{\partial x}+f_D Q_x=0 \tag{2a}$$

$$\frac{\partial Q_y}{\partial y}+C^2\frac{\partial\zeta}{\partial y}+f_D Q_y=0 \tag{2b}$$

$$\frac{\partial\zeta}{\partial t}+\frac{1}{n}\left(\frac{\partial nQ_x}{\partial x}+\frac{\partial nQ_y}{\partial y}\right)=0 \tag{3}$$

Where, Q_x, Q_y : Line flow rate, ζ : Water-surface fluctuation, n : Ratio of wave velocity to group velocity, f_D : Wave-breaking attenuation.

The actual numerical calculations are carried out by converting these basic equations into finite-defference equations against the array of calculation points for various parameters on the grid mesh and giving boundary conditions as necessary.

3.3. Wave-field calculation results

At first, in order to examine the effect of artificial reefs on the wave field, the distribution of wave heights in Hamanaka Bay was calculated by applying TDMSE to the seabottom topography before and after installing the artificial reefs in the wave-field calculation area (with and without hatch) shown in Fig. 9. In this calculation area, it is necessary to pay attention to the range of effects the artificial reefs or coastal topography have on sea waves, so conditions were established in such a way that the diffraction effect of waves from Kiritappu

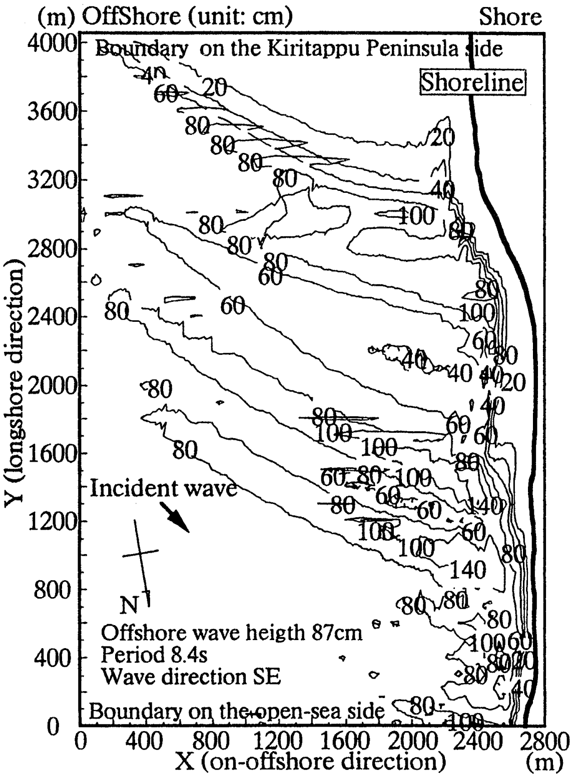


Fig. 10 Results of wave field calculations before installing artificial reefs (TDMSE).

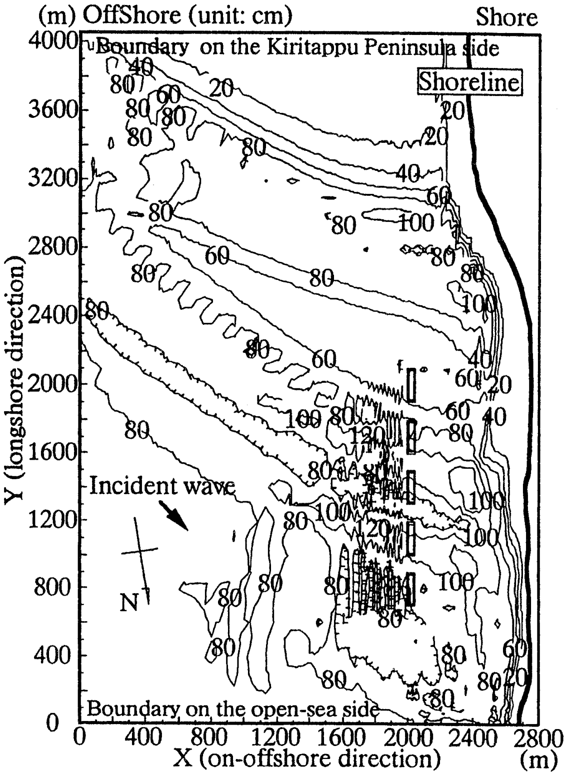


Fig. 11 Results of wave field calculations after installing artificial reefs(TDMSE).

Peninsula could be considered, including all groups of 5 artificial reefs. The boundary condition was established as an incident boundary which gives a significant wave parameter in the offshore boundary. The boundary on the side of Kiritappu Peninsula was assumed to be a closed boundary without input of line flow rate. The boundary on the open-sea side and the boundary on the shore side were assumed to be open boundaries. Each artificial reef has the following parameters : 200 m in dike length (Lr), 100m in opening width (W) and 800m in offshore distance (Y), which are similar to those on the site. Working wave conditions are as follows : offshore wave height Ho=87cm, period T=8.4 s and wave direction SE, according to typical wave parameters from on-site observations.

Under these conditions, calculations were made on the plane wave field by applying TD-MSE to the seabottom topography before and after installing the artificial reefs, and their results are shown in Figs. 10 and 11, respectively. Looking at the wave field before installing the artificial reefs, the waves entering from the direction of SE are affected by diffraction from Kiritappu Peninsula which is located in the south of the bay, and the wave height is small in the vicinity of the peninsula. The wave height in the on-offshore direction in the area near Y=1500m underwent a change in refraction due to offshore seabottom topography, thereby causing shoaling toward the coast. After growing into about 140cm, the wave height faces the breaking point, attenuates and reaches the shoreline. Looking at the wave field after installing the artificial reefs, reflected waves are produces in the front part of the breakwater, while in the hinterland the wave height is attenuating about 30% as compared with that before installing the artificial reefs. Thus, the wave control effect of artificial reefs

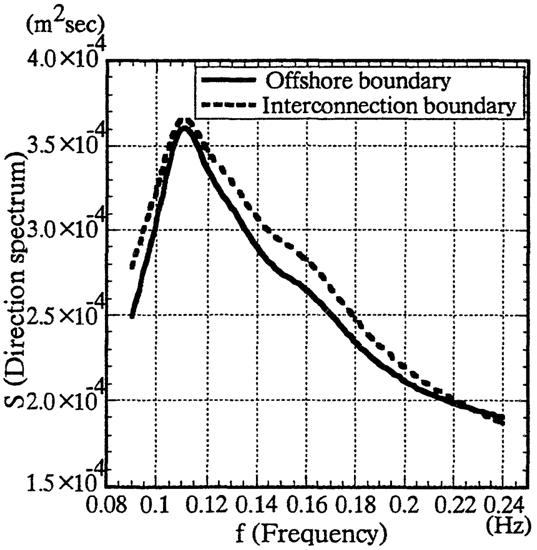


Fig. 12 Main wave direction spectrum.

is evidently seen, possibly providings a favorable place for bivalves to live in.

Next, the sea area (with hatch) around the artificial reefs shown in Fig. 9 was considered as a study area, and interconnection calculations were carried out to estimate the wave field by applying EBE in the sea off the study area and using TDMSE in the sea within the study area. When interconnecting the two wave models, significant wave parameters were obtained from the results of EBE direction spectrum calculations as input conditions to TDMSE.

The boundary condition in the EBE calculation area (without hatch + with hatch) was established as the incident boundary which gives a direction spectrum so that the irregularity of waves can be considered by on-site observations. The open-sea boundary and coastal boundary are assumed to be open boundaries, with the same spectrum in and outside the calculation area. The boundary on the side of Kiritappu Peninsula is assumed to be a closed boundary, with no energy input.

The results of direction spectrum calculations by EBE under the conditions mentioned above are as follows. Figure 12 shows the main wave direction spectrum between the offshore boundary and the interconnection boundary, with the energy of waves concentrated in the neighborhood of f=0.11 Hz. The total energy of waves is obtained from the direction spectrum, which is the converted into significant wave height $H_{1/3}$. Consequently, $H_{1/3}$ is about 78 cm. The distribution of wave heights in the interconnection calculation with this significant wave height given to TDMSE as input condition in the interconnection boundary, is shown in Fig. 13. The distribution shows that in the front part of the artificial reefs, reflected waves are produced ; in the hinterland, the wave height attenuates and after that, waves are reproduced causing the wave height to increase again. Comparing the wave height distributions shown in Figs.13 and 11, the tendency of the wave height to reach about 100cm in the coastal direction over X=2400~2500m is appearing in both, though difference is recognized in the distribution of wave heights in the coastal direction near X=2100m. This is due to

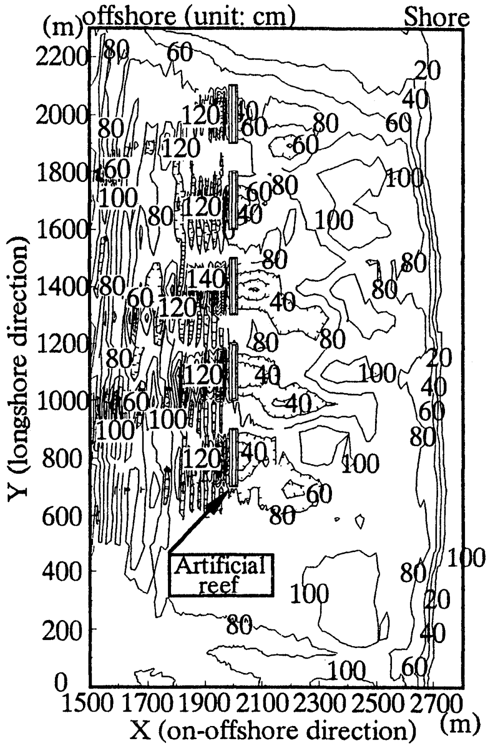


Fig. 13 Results of interconnection calculations of the wave field.

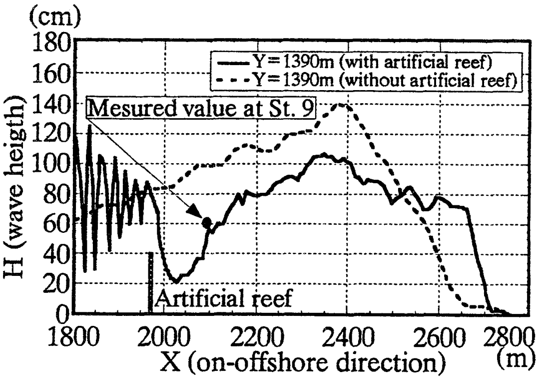


Fig. 14 Comparison of calculated values and on-site observed values.

the effect of difference in the wave height distribution in the neighborhood of the interconnection boundary. That is to say, in Fig. 11, a sign wave is given in the offshore boundary, and a solution by TDMSE is calculated, hence the wave-height fluctuation in the entire calculation area becomes conspicuous due to the phase interaction of waves. On the other hand, EBE solves the energy transport status of irregular waves, thereby obtaining a solution to more smoothened wave-height distribution than TDMSE. In Fig. 13, this smoothened wave-height distribution is input in the interconnection boundary, possibly causing a difference from Fig. 11. In Fig. 14, changes in wave height with and without artificial reefs at Y=1390m shown in Figs.10 an 13 are plotted in the on-offshore direction to make comparison with the on-site observed values. The wave height with artificial reefs in the hinterland is smaller than that without artificial reefs, and in the neighborhood of X=2000m, the wave height is showing a sudden decrease owing to forced breaking by the artificial reefs. It seems that such a decline in the wave height reduces the bottom orbital velocity which is in proportion to the wave height, making it possible to contribute to the increased stability of the habitat. Also, the calculated values are almost similar to the observed values at St. 9.

When the identification of a wave phenomenon that can be controlled by coastal structures for the habitat stabilization of bivalves becomes an important problem, as in Hamanaka Bay, it will be more effective to apply TDMSE which can comprehensively evaluate all wave deformations around the artificial reefs and apply EBE in the sea area where waves waves are not affected by the artificial reefs. As one of the advantages to make such interconnection calculations, shorter computation time is pointed out, with the CPU occupation time for interconnection calculations being about 1/4 of TDMSE only.

3.4. Numerical simulation on the nearshore current field

When an attempt is made to control the dissipation of bivalves' planktonic larvae or promote their implantation, a possible method is to weaken the velocity of flow or change the flow patten by installing artificial reefs. In this section, therefore, numerical simulation is carried out on the nearshore current filed to examine the effect of the artificial reefs installed in Hamanaka Bay on the flows in the surrounding sea areas.

3.5. Basic equation

The flow near the coastal zone, which occurs due to sea waves, is generated owing to the gradients of radiation stresses in the on-offshore direction and coastal direction. The orthogonal coordinates are taken within the horizontal plane and defines the on-offshore axis in the x direction and the longsshore axis in the y direction. The equation of continuity is as described below with each component of the mean flow assumed to be U and V and the mean sea level, ζ.

$$\frac{\partial \xi}{\partial t}+\frac{\partial U(h+\xi)}{\partial x}+V\frac{\partial V(h+\xi)}{\partial y}=0 \tag{5}$$

Also, the equation of motion containing the radiation stress is given by the following :

$$\begin{aligned}&\frac{\partial U(h+\xi)}{\partial t}+U\frac{\partial U(h+\xi)}{\partial x}+V\frac{\partial V(h+\xi)}{\partial y}\\&=-g(h+\xi)\frac{\partial \xi}{\partial x}\\&+\frac{\partial}{\partial x}\left\{\varepsilon_x\frac{\partial U(h+\xi)}{\partial x}\right\}+\frac{\partial}{\partial y}\left\{\varepsilon_y\frac{\partial U(h+\xi)}{\partial y}\right\}\\&-\frac{1}{\rho}\frac{\partial S_{xx}}{\partial x}-\frac{1}{\rho}\frac{\partial S_{xy}}{\partial y}-\tau_{bx}\end{aligned} \tag{6a}$$

$$\frac{\partial U(h+\xi)}{\partial t}+U\frac{\partial U(h+\xi)}{\partial x}+V\frac{\partial V(h+\xi)}{\partial y}$$
$$=g(h+\xi)\frac{\partial \xi}{\partial y}$$
$$+\frac{\partial}{\partial x}\left\{\varepsilon_x\frac{\partial V(h+\xi)}{\partial x}\right\}+\frac{\partial}{\partial y}\left\{\varepsilon_y\frac{\partial V(h+\xi)}{\partial y}\right\}$$
$$-\frac{1}{\rho}\frac{\partial S_{yx}}{\partial x}-\frac{1}{\rho}\frac{\partial S_{yy}}{\partial y}-\tau_{by} \qquad (6b)$$

Where, the fourth and fifth terms in the right side are radiation stress terms which are difined as the excess momentum flux of waves, while the sixth in the right side is a seabottom friction term.

Eddy viscosity coefficients ε_x and ε_y are expressed by the equation (7) according to the hypothesis of LONGUET-HIGGINS (1970).

$$\varepsilon_{x,\,y}=N\ell\sqrt{g(h+\xi)} \qquad (7)$$

Where, N : Non-dimensional constant in the order of 0.01, ℓ : Offshore distance Numerical calculations are perfomed by converting equation (5) and equations (6a, 6b) into the finite difference equation against calculation points for various parameters defined on the grid mesh. Meanwhile, the radiation stress of progressive waves which become a nearshore-current driving force was calculated using the wave energy and wave direction from the results of wave-field calculations and was given to the equation of motion.

3.6. Results of nearshore-current field calculations

The nearshore-current study area was established by paying attention to that the range of effects by a group of artificial reefs should be included as shown in Fig. 9, the depth contour changes gently in the longshore direction, etc.

Figure 15 shows the results of calculations on the nearshore current field before installing the artificial reefs. The circulation flow centering around X=2400m, Y=1250m and X=2500m and Y=1500m is recognized. These positions correspond to a portion in which the wave height declines from maximum 140cm to about 60~80cm in the longshore direction, according to the results of wave-field calculations shown in Fig. 10. If the wave-height distribution is not uniform in the longshore direction, the sea-water accumulated near the shore under equilibrium condition must be returned to the offing, thereby generating such an offshore current (trip current). As a current that compensates the rip current, the longshore current develops in the almost same direction as the incident angle of waves, producing a large velocity value. HARRIS (1969) assumes that the frequency of causing such an assymetric-cell nearshore current is about 50% of the nearshore current system in the case where waves enter obliquely in the natural coast.

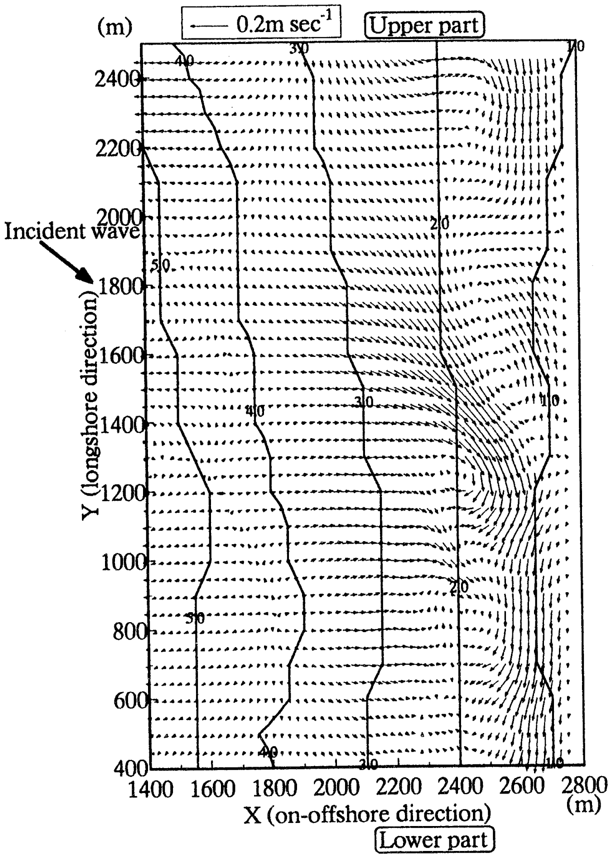


Fig. 15 Results of calculations on the nearshore current before installing artificial reef.

Figure 16 shows the results of calculations on the nearshore current field after installing the artificial reefs. For radiation stress, the values obtained from the results of wave-field calculations shown in Fig. 13 were used. The

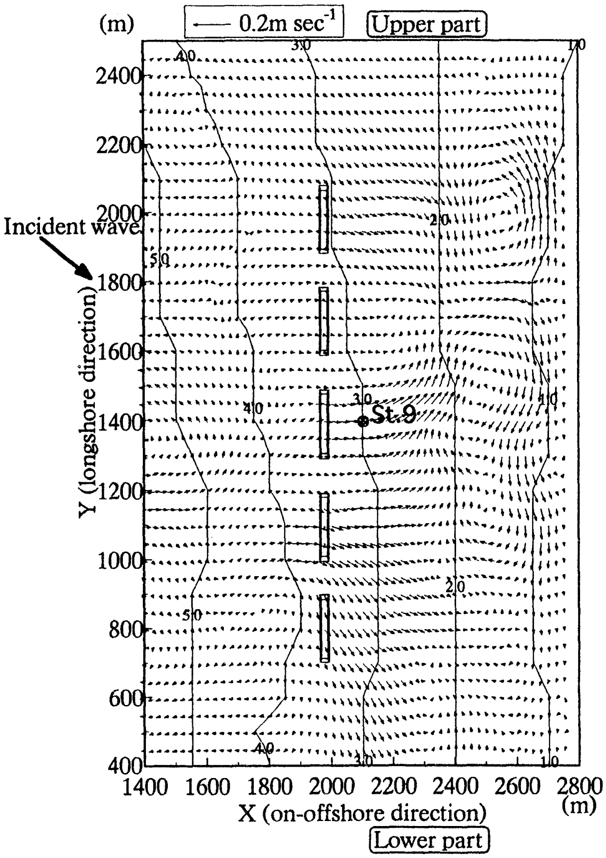


Fig. 16 Results of calculations on the nearshore current after installing artificial reef.

greater part of the flow near the shore is heading from the upper part toward the lower part, and the flow direction in the vicinity of X =2500m, Y=900m where the flow velocity becomes weak is changed toward the offshore side, forming a large circulation flow in the hinterland zone. Also, part of it heads from the lower part toward the upper part, which is contrary to the incident direction, and overlaps the current which flows downward from the upper part, forming a small counterclockwise circulation flow. If waves enter obliquely against a group of artificial reefs, a bilaterally assymetric circulation flow is generated in the hinterland zone, and its velocity is weakened near the shore as compared with the case where there is no artificial reef. The velocity obtained by on-site observations at St.9 was about 4 cm sec^{-1} and the velosity at the calculation point corresponding to St.9 was 4.2 cm sec^{-1}, hence it can be said that the observed value agreed almost with the calculated value.

The nearshore current mainly affects the migration of shells, the diffusion of egge and larvae and the promotion of implantation. WATANABE (1982) reports that the critical velocities for migration of bivalves (specific gra vity : 1.32) whose shell lengths are 1, 3 and 5 cm are about 29, 40 and 50 cm sec^{-1}, respectively, in the case where there are sand ripples on the seabottom. In the nearshore-current calculation in the case where artificial reefs were installed, the maximum velocity is estimated at about 12.6 cm sec^{-1}, which is lower than the critical velocity for the migration of shells, and it can therefore be considered possible to prevent the runup of shells exposed from the bottom surface. Also, in the water area behind the mound, the velocity with artificial reefs was found weaker than that without artificial reefs, thus the retention time of larvae within the water area becomes longer, possibly promoting their implantation.

4. Conclusions

With the habitat stabilization of bivalves in mind, plane movable bed tests on the nearshore current and littoral drift phenomena around the artificial reef and numerical simulations on the wave field and nearshore current field around a group of artificial reefs installed in Hamanaka Bay were carried out, and hydraulic characteristics were examined. As a result, the following conclusions were drawn up :

(1) The peculiar nearshore current which is generated around the artificial reef depends on changes in the length of the dike and the length of the opening width, and the longer the opening width the more likely the circulation flows occurs. If the classification of circulation flow occurrence patterns is indicated according to the dike length and opening width, it may be broadly classified into the following three zon es : Zone in which a stable circulation flow is generated with $0 < Lr/W \leq 4$, zone in which an unstable circulation flow is generated with $4 < Lr/W \leq 6$, and zone in which an on-offshore flow is generated with $6 < Lr/W$. Using this

flow pattern classification, a steady circulation flow is formed in the nearshore current and planktonic larvae are trapped in the water mass in it, so that the dissipation of larvae can be controlled.

(2) The wave height in the case where a group of artificial reefs were installed in Hamanaka Bay was found about 30% lower than that without artificial reefs. The nearshore current field generated a stable circulation flow by installing the artificial reefs, and the velocity of flow near the shore was found weakened. It can be considered that the control of sea waves and flows using these artificial reefs will mitigate the outflow of bivalves' planktonic larvae and promote their implantation, possibly leading to the creation of an ideal habitat.

Although this research is confined to a study on the control of waves and flows by the artificial reef, it will provide useful information in the foundamental stage to identify the hydraulic characteristics these structures give to the habitat.

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Original Achievements Leading Inductively Towards Quantitative Evaluation of Detritus Food Chains in the Marine Food Web

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Abstract : Representative studies conducted originally to the reasonable assessment on significance of detritus food chains in the marine food web for the stability of marine ecosystems have been reviewed from the point of views of both(1)the feeding types of animals comprising the food web, and(2)the energy flow among marine communities in the world oceans.

The former view is evident from the fact that many marine animal species do not conform to specific trophic levels, and the ability of a given species to utilize alternative foods has a great buffering action which tends to stabilize population sizes in the complex marine ecosystem communities.

The latter can be evaluated by comparing the potential solar energy available for primary production in the world oceans, the actual primary productivity measured in the world oceans, and the possible productivity calculated from the commercial fish catch.

Carbon Budget of the Marine Ecosystem Assuming Predominance of the Grazing Food Chains

As in any ecosystem of the Biosphere, the food chains in the marine ecosystem have been shown to be of two basic types; (1) the grazing food chain, which starts from a plant base to grazing herbivores, and on to carnivores, and (2) the detritus food chain, which goes from dead organic matter to heterotrophic microorganisms, and then to detritivores and their predators.

Even at present, most textbooks and encyclopedias describe the grazing food chains as being predominant in the marine ecosystem in contrast with the predominance of detritus food chains in terrestrial ecosystems. The greatest symbolic illustration of this concept goes back to a famous picture of the marine food web in "The nature of oceanic life" by ISAACS in Scientific American (1969). With this conventional agreement that the grazing food chains are predominant in the marine ecosystem, many sophisticated efforts have been made among the greatest authorities to estimate the solar energy available to the marine community in the world oceans (OPPENHEIMER ed., 1968).

Here, based on the solar energy available for photosynthesis in the world oceans, the theoretically maximum productivity of the oceans is calculated as 1.6×10^{11} tons of carbon per year.

Next, this theoretically maximum productivity of the oceans is examined by comparing it with the actual primary productivity measured in the marine ecosystem. As referred to primary production measured actually at different regions of seas and oceans, the annual productivity measured in the world oceans should be summarized as 5.3×10^{10} tons of carbon; that is roughly one third of the theoretical maximum productivity of the world oceans.

Finally, the theoretically maximum productivity of the oceans is examined also by comparing with the primary productivity

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calculated from the commercial fish catch in the world oceans, based on the transfer of food energy with repeated eating and being eaten through a series of prey–predator relationships leading back to the energy source of primary producers in the marine ecosystem.

For this calculation, the amount of commercial fish catch in 1961 was from FAO Fisheries Statistics, by assuming three links in the food chain, with a 5% ecological transfer efficiency. The efficiency is one of the minimal estimations (STEELE ed., 1970), but it must be appropriate in this calculations because there is much energy consumption for the seeking and chasing of a prey by a predator in such an oligotrophic environment as most parts of the oceans. Thus the annual productivity is evaluated as 5.8×10^{10} tons of carbon, that is pretty close to the annual productivity measured in the world oceans.

The conclusion was made at the symposium (OPPENHEIMER ed., 1968) that the annual primary productivity is getting to be within an order of magnitude of the maximum productivity possible, and that the actual harvest of fishery products from the world oceans is getting very close to what is being put into the world oceans. However, we must realize that the estimation by the actual measurement of primary productivity is based only on the phytoplankton, from which transformation of the grazing food chains starts. We must recall also that the actual harvest of fisheries products from the world oceans in 1961 was half of that in the 1980s (FAO, 1991). The cybernetic system of biological productivity in the oceans should not be so inefficient in the utilization of solar energy to be as low as one third of the theoretical maximum productivity!

Carbon Budget of the Marine Ecosystem With Both Grazing and Detritus Food Chains

The conventional agreement that the grazing food chains could be predominant in the marine ecosystem is definitely inadequate because phytoplankters are shown not to be harvested efficiently by grazing zooplankters (PORTER, 1973). Chains of diatoms are broken while they are grasped by zooplankton, and a part of diatoms is damaged and lost. Rough estimates of the grazing efficiency of phytoplankton by zooplankton under natural conditions vary from 90% to 50%. Zooplankters graze an over-abundance of phytoplankton food, far in excess of their needs, and excrete half or more as faecal pellets. This semi-digested phytoplankton detritus has been reported to often form a significant fraction of particulate organic materials in coastal waters (STRICKLAND, 1965).

Virus infection has been shown recently as another important factor to make phytoplankton flow directly into the ocean debris (*e.g.*, SUTTLE *et al.*, 1991), since a high abundance of viruses were found in aquatic environments by BERGH *et al.* (1989).

Ever since the first aggressive claim with scientific evidences by STRICKLAND (RILEY ed., 1963) to make conservative ecologists realize that the greater fraction of organic material in the oceans is comprised of non-living debris, marine macrophytes have received attention as a major potential source of the particulate and dissolved organic matter in sea water, because less than 5% of macrophytes production has been determined to enter the marine food web by direct grazing, in spite of the fact that the macrophytic communities and mangroves of coastal regions tend to develop to be highly productive (*e.g.*, up to 2,000 gC m^{-2} per year). The evidence that marine macrophytes generate debris rather than enter the grazing food chains has thus been recognized in many species of kelps, sea grasses, rockweeds, marsh grasses and mangrove (MANN, 1972). With a careful assessment of annual primary production of these major marine macrophyte systems, the production range have been estimated from 50 to 2,000 gC per square meter, and certain kelp beds are more productive than the most productive land, such as an intensively managed alfalfa field! MANN (1972) concluded that the macrophyte fringe of the oceans has an intensity of production which is up to 40 times the intensity of phytoplankton production. Assuming that the area of macrophyte fringe occupies the coastal region above 10 m deep, the fringe dominates 1.0% of the world oceans, *i.e.*, based on 7.6% area of continental shelf in the oceans (KOSSINNA, 1921) and

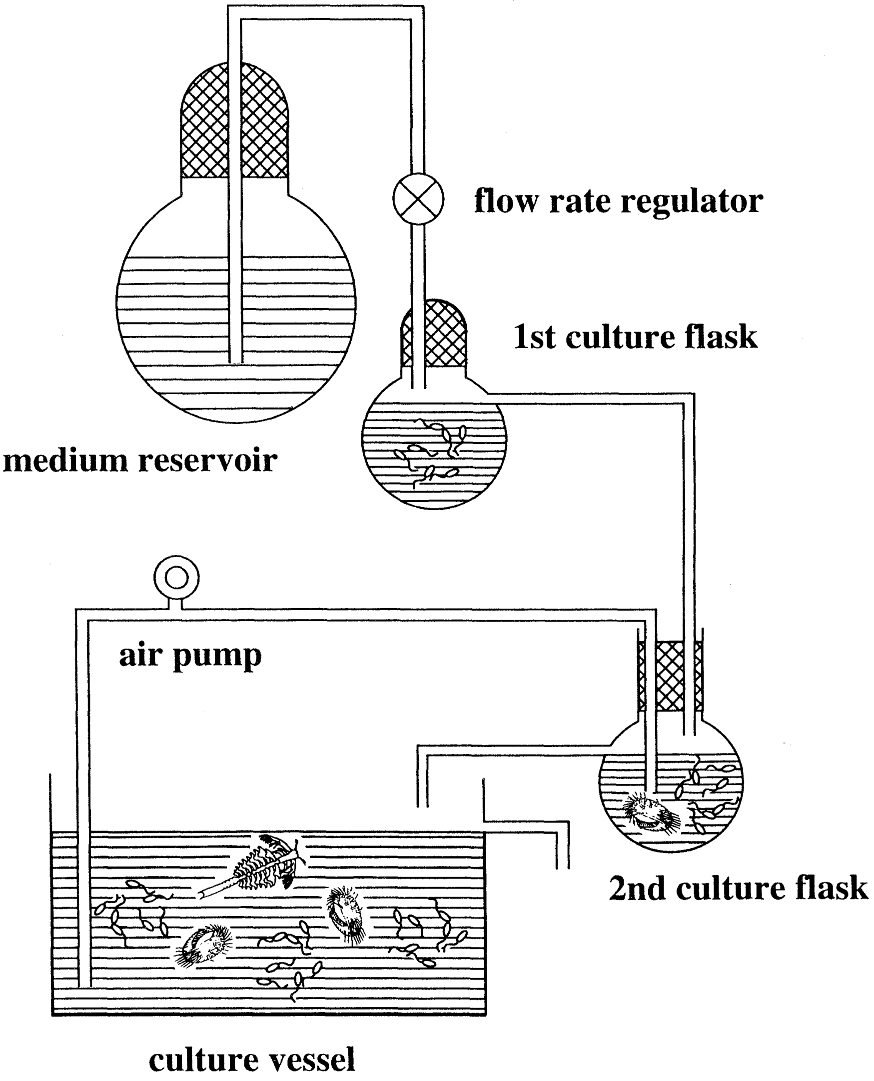

Fig. 1. A continuous culture system for the culture of bacteria, protozoa and brine shripms. Bacteria and protozoa were isolated from the sea water of Aburatsubo Inlet, Japan (modified from SEKI, 1966)

the hypsometric curve of surface of the earth (WYLLIE, 1976). By comparing the production intensities and distribution areas, the primary production by macrophytes is evaluated as much as up to 40% of that by phytoplankton in the marine ecosystem. In addition to this evaluation, the primary production by floating seaweeds such as *Sargassum* in the surface of open oceans must be taken into account as macrophyte production of the world, because its production is considerable in such convergence areas as in Shiome(current rip)and the Sargasso Sea.

The process of detritus production from living macrophytes is continuous; *i.e.,* as they grow, leaves or leaf tips die and start to disintegrate. Most grazers on macrophytes are known to be very inefficient, wasting more than they consume and thus contributing to the detritus supply. Once these macrophytes die, the dead

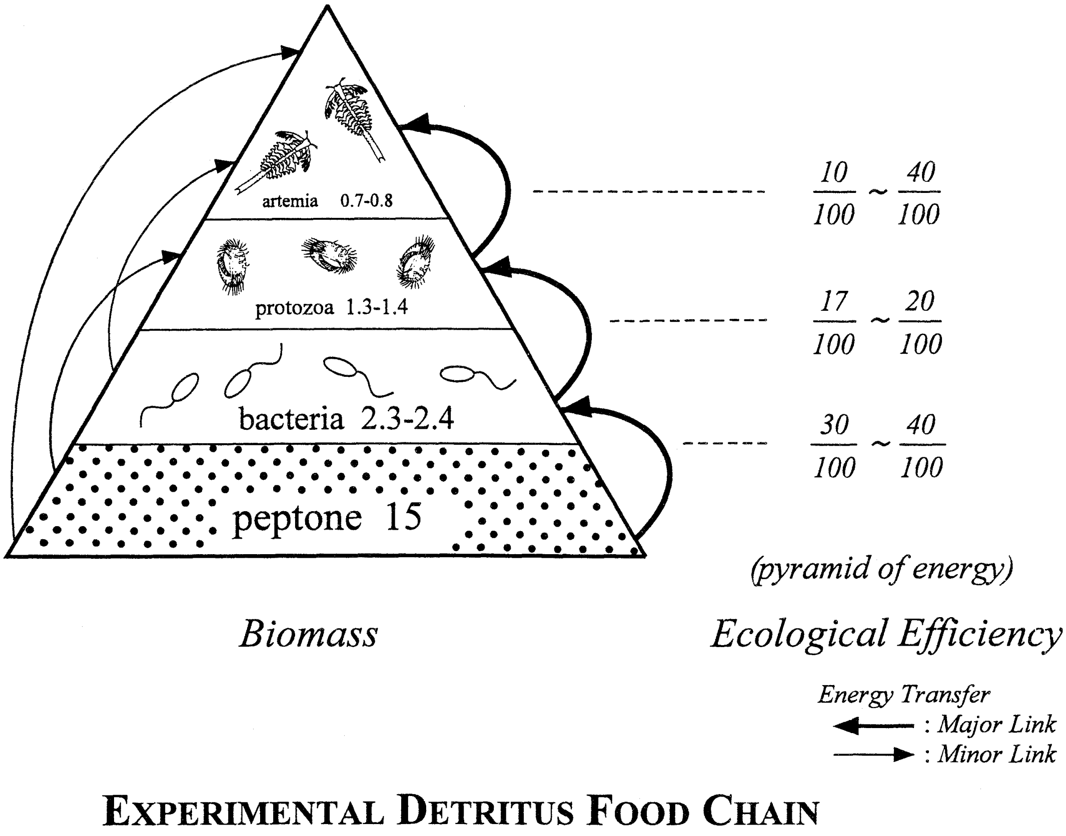

Fig. 2. Ecological pyramids based on (1) the biomass of organisms consumed and (2) energy transfer (biological production) from each trophic level of the pyramid of the detritus food chain in the experimental system in Fig. 1

plant materials are covered by bacterial colonies, which support populations of protozoa and other micro-detritivores. Whole microbial communities on a dead macrophyte piece are ingested by fishes and macro-invertebrates as described in DARNELL(1961). These macro-detritivores have been shown to digest only micro-detritivores and bacteria, because their faecal pellets consist almost exclusively of dead macrophytal material (MANN, 1972; SEKI, 1982a). The faecal pellets are recolonized by microbial populations, and the same process is repeated. With every cycle, the particle size of the dead macrophyte piece is reduced. While processes of the detritus food chains proceed, a part of macrophyte production enters into the stock of ocean debris as a dissolved form.

The energy transfer in an experimental system of the detritus food chain (Figs. 1 and 2) was determined firstly by SEKI (1964, 1965, 1966b). Thereafter, efficient bacterial utilization of these abundant organic materials, both from dead phytoplankton and macrophyte, as the production at the primary trophic level of detritus food chains has been shown with both experimental and field studies by many authors (*e.g.*, PARSONS and SEKI, 1970; SEKI, 1969; 1971; 1972; SEKI *et al.*, 1968; 1969; 1972; 1974a; SEKI & YOKOHAMA, 1978).

Difficulty in Classification of The Real Trophic Level of A Species in the Marine Ecological Pyramid

The mythology of the grazing food chains being predominant at the marine ecosystem was also doubted in 1961, since DARNELL (1961) showed that many animal species do not conform to specific trophic levels, based on the results of a series of detailed investigations obtained in a large estuary of the Louisiana coast.

There are only a few typical carnivorous fish species, such as longnose gar, crevalle jack, bull shark and southern flounder. The really abundant fish and invertebrate species comprise 2 groups: The first includes those omnivorous species which have a rather wide range of food tolerance, such as sea catfish, bay anchovy, spot, Atlantic croaker and blue crab. The second includes those detritivorous species which feed largely upon organic detritus, such as rangia clam, striped mullet, largescale menhaden, white shrimp and hogchoker.

The ontogenetic progression of food habits within a given species frequently involves successive specialization upon different types of foods. This is evidently shown in case of the Atlantic croaker; i.e., the successive shift or its prey proceeds from zooplankton to small benthic animals, then to detritus, and finally to larger crustaceans and fishes.

Hence the study by DARNELL (1961) shows that the ability of a given species to utilize alternative foods has a great buffering action which tends to stabilize population sizes in the complex communities of the marine ecosystem. It was also shown that most of the marine consumer species ingest large quantities of organic debris and some of them are largely dependent upon this material. These conclusions evidently lead also to the importance of the detritus food chains from the predator side of the marine ecosystem.

Stability of the Marine Ecological Pyramid With the Backup System of the Detritus Food Chains

The difficulty of classifying a marine species into a particular trophic level in the marine ecological pyramid is not only seen in the case of predator but also for prey. As has been recently realized(*e.g.*, SIEBURTH *et al.*, 1988), many flagellate species play roles as detritivores as well asprimary producers. Their grazing mechanism has been clarified, especially for species in the haptophyta. Food capture and transport during phagocytosis of these flagellates has been shown clearly using video images for a species *Chrysochromulina hirta* (KAWACHI *et al.*, 1991). Existence of these mixotrophs can stabilize the biomass within the first trophic level of the marine food web towards a very steady state, by efficiently collecting bacterioplankton and the detritus which is released mainly from dead macrophytes and the broken phytoplankton from zooplankton grazing, natural death and virus infection. Thus, constituent members in the first trophic level of marine ecological pyramid comprise these primary producers in the grazing food chains and the detritus food chains; both producers acting as replenishing agents against the loss of organic materials to make the organic debris loss as small as possible. Already by a purely theoretical approach, PARSONS and KESSLER (1986) have predicted this important role of zooflagellates in maintaining an adequate food supply for zooplankton when the phytoplankton has run out of nutrients and collapses.

The major constituent member in the first trophic level of detritus food chains are bacteria which are not only dependent on detrital particles but also on dissolved organic materials. An early study of bacterial production through this process was initiated by PARSONS and STRICKLAND (1962) in order to determine the significant part of photosynthestic production flows via bacteria through the detritus food chains in the marine ecological pyramid. An analysis which greatly contributed to the reliable understanding of the distribution of the organic debris was made by DUURSMA (1960), who determined its approximate biomass as 1 mgC per liter of sea water in the bulk of the ocean. Each organic compound is maintained in a steady-state equilibrium in the order of μg per liter, down to a threshold in the order of ng per liter by bacterial nutrient assimilation in some oligotrophic waters. As much as 5 to 10 times of this concentration occurs within surface waters and throughout the coastal waters, and it is rarely less than 0.5 mgC per liter in deep ocean waters (*e.g.*, SEKI *et al.*, 1974b; 1981a; 1981b). This minimum concentration is the apparent threshold bulk of most

Table 1
Primary production divided into the grazing and
detritus food chains in the world oceans

PRIMARY PRODUCTION(100%)IN THE WORLD OCEANS BY:	
PHYTOPLANKTON: 71%	
used for grazing by zooplankton ;	13% ~ 23%
used for generating debris ;	48% ~ 58%
MACROPHYTES: 29%	
used for grazing by benthos;	< 1.5%
used for generating debris;	27% ~ 28%

* Overall energy of the primary production to be used for

(1) the grazing food chain is between 14% and 24%
(13%~23% used for grazing by zooplankton, and
< 1.5% used for grazing by benthos)
and
(2) the detritus food chain is between 75% and 86%.
(48%~58% used for generating debris, and
27%~28% used for generating debris)

organic compound; more than 0.5 mgC per liter of organic debris are susceptible to dynamic cycling by the bacterial action (SEKI, 1992).

The bacterioplankton production through debris utilization in the world oceans seems to be insignificant because the aquatic humus comprises the major fraction of total organic debris. The annual flux corresponds to 0.20×10^9 tons of carbon in the world oceans, assuming that the total debris amount of 1.3×10^{12} tons of carbon(SKOPINTSEV, 1966)then the resident time of 3740 years (WILLIAMS *et al.*, 1969) is determined be converting 30% into bacterial cells. This amounts to only 0.02% of the maximum primary productivity.

However, when the process is specified within the productive layer of oceans, assuming a value of roughly 0.1 mgC per square meter for the standing crop of bacterioplankton which can utilize highly nutritional organic solute excreted from both living plants and animals (PARSONS and SEKI, 1970; SEKI, 1966a; 1970a; 1970b; SEKI and ZOBELL, 1967), the bacterioplankton production there is as much as 0.5 to 1% of the phytoplankton production (PARSONS and STRICKLAND, 1962). This moderate transfer efficiency is due to rapid cycling of easily metabolizable solutes (*e.g.*, organic acids, monosaccharides and amino acids) with their resident time as short as several tens of days (SEKI, 1992). This contribution of bacterioplankton is still extremely small, when compared with that of attached bacteria on the dead macrophytes and the faecal pellets of dead phytoplankton (SEKI, 1970a; SEKI *et al.*, 1972; HONJO, 1978).

As mentioned before, the grazing efficiency of phytoplankton by zooplankton in the oceans varies from 50 to 90% even if there is an ideal prey–predator relationship without the grazing loss. As such an ideal period for grazing has been observed to be only less than 3 months a year in the world oceans (HEINRICH, 1962), less than 25% of the annual primary production can be used for the grazing food chains of marine ecological pyramid. The approximate calculations, thus, lead to the definite conclusion that the detritus food chains are dominant over the grazing food chains in the marine ecosystem, just the same as in the terrestrial ecosystems (Table 1).

Approximately equal concentrations of organisms have shown to occur at every particle size group within the range from phytoplankton to whales in Antarctic waters or from phytoplankton to tuna in the equatorial Pacific

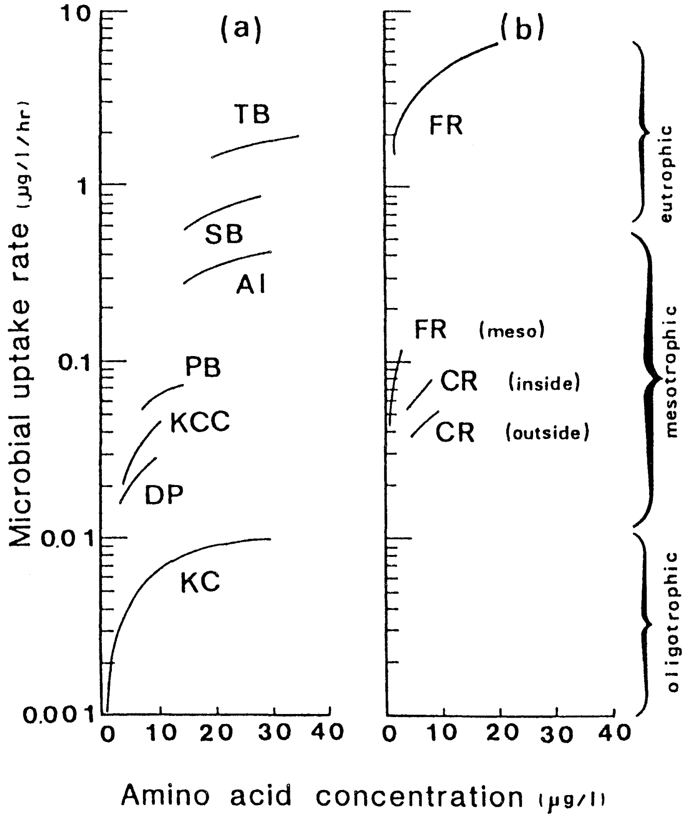

Fig. 3. Assimilation of amino acids by natural microbial communities (95% confidence limits) at Kuroshio Current(KC), Kuroshio Counter Current (KCC), Shimoda Bay (SB), Tokyo Bay (TB), Discovery Passage (DP), Patricia Bay (PB), Alberni Inlet (AI) in the Pacific coast (a); and at Campbell River Estuary (CR) and Fraser River Estuary (FR) in the Canadian estuaries (b) (reproduced from SEKI, 1992)

Ocean (SHELDON *et al.*, 1972). The same biomass structure is kept even with the addition of the bacterial size group into the scheme (SEKI, 1982a). In the structure, some decrease of standing stock actually determined in the oceans may occur as particle size increases, so the pyramid of biomass has a slightly upright shape. However, concentrations in the bacterial and phytoplankton size ranges should be reduced by a factor of at least two to eliminate living organisms only. The zooplankton concentrations are approximately correct, as it is unlikely that many nonliving particles are present in that size range. The estimated concentrations of tuna and whales represent minimums for particles of these sizes due to technical problems in estimation. When these corrections are performed to estimate standing stocks of living particles, the constant concentrations represent the possible spectrum of living particles in the Antarctic and equatorial Pacific Oceans. The pattern of standing stocks are similar in each of the two oceans, although the absolute values differ by approximately a factor of ten. This could be reasonably expected because of differences in the productivity of each region.

The arithmetic distribution of biomass in any ocean must be a column shape. Then the pattern of this standing stock can be maintained only if the rate of production varies inversely with particle size, in order that the

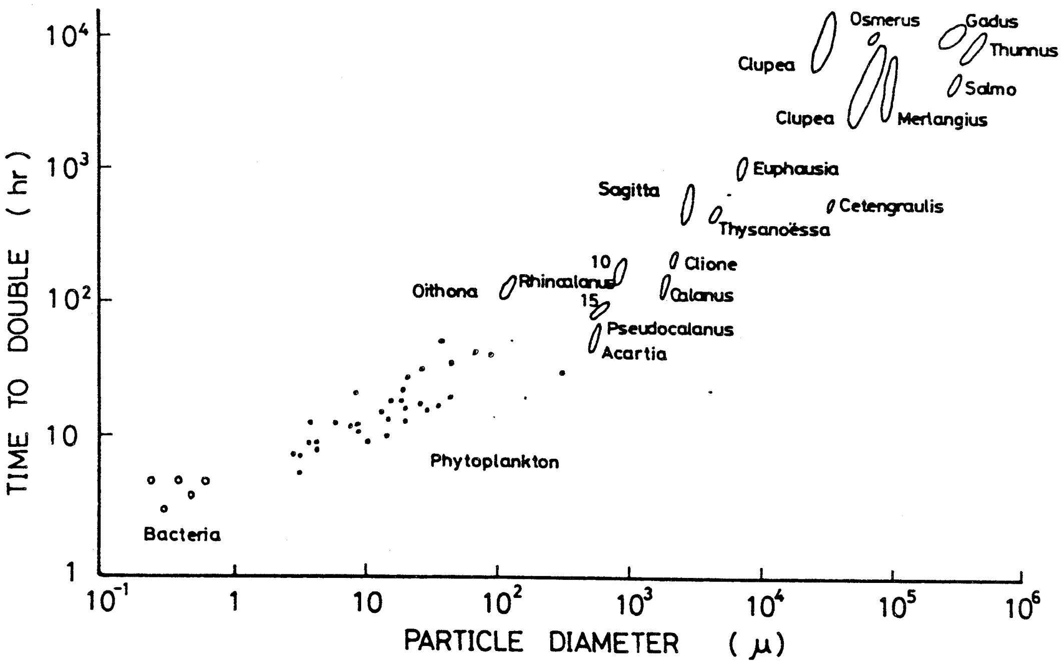

Fig. 4. The relationship between production rate and particle size (modified from SHELDON *et al.*, 1972)

pyramid of energy can reasonably take a true upright pyramid shape. This is evident in Figure 4 which shows the relationship between production rates and particle sizes of all groups of marine organisms including bacteria. A striking characteristic of bacteria and other nanoplankters is their rapid rates of reproduction, accomplished by vegetative cell division. Their biomass formation can be extremely rapid since the increase is by geometric progression. The rate of bacterial division is as frequent as once every few hours in the production layer, where bacterioplankton acts as a replenishing agent against the loss of organic materials from phytoplankton to make the organic debris losses from the marine ecological pyramid as minimal as possible. The growth rate and size of a multi-cellular organism vary significantly during its life-time, whereas a single-celled microbe is less variable. Growth rate of marine microorganisms varies greatly with temperature and other environmental factors in usual laboratory experiments, but this effect has been determined to be relatively small with prompt biological reactions such as the species succession and other phenomena in the natural environment of oceans (SEKI, 1982b).

When organisms in both grazing food chains and detritus food chains at each trophic level of the marine ecological pyramid are related as whole (size ranges; 10^{-1} to $10^2 \mu m$ for the first trophic level, 10^2 to $10^4 \mu m$ for the second trophic level, 10^4 to $10^6 \mu m$ for the third trophic level), production rates between prey and predators vary by roughly one order of magnitude (Fig. 5). Although experimental results represent higher efficiencies almost exclusively due to the predator's assimilation, those efficiencies in Nature must include also energy loss of finding and accessing the prey by predator. Therefore, some experimental results have shown that the energy transferred from one trophic level to another can be more efficient than 30% (STEELE ed., 1970), but the standing stocks of every trophic level is kept similar with the ecological efficiency of about 10% in the oceans.

Finally, the bacterial production processes are less susceptible to seasonal and other

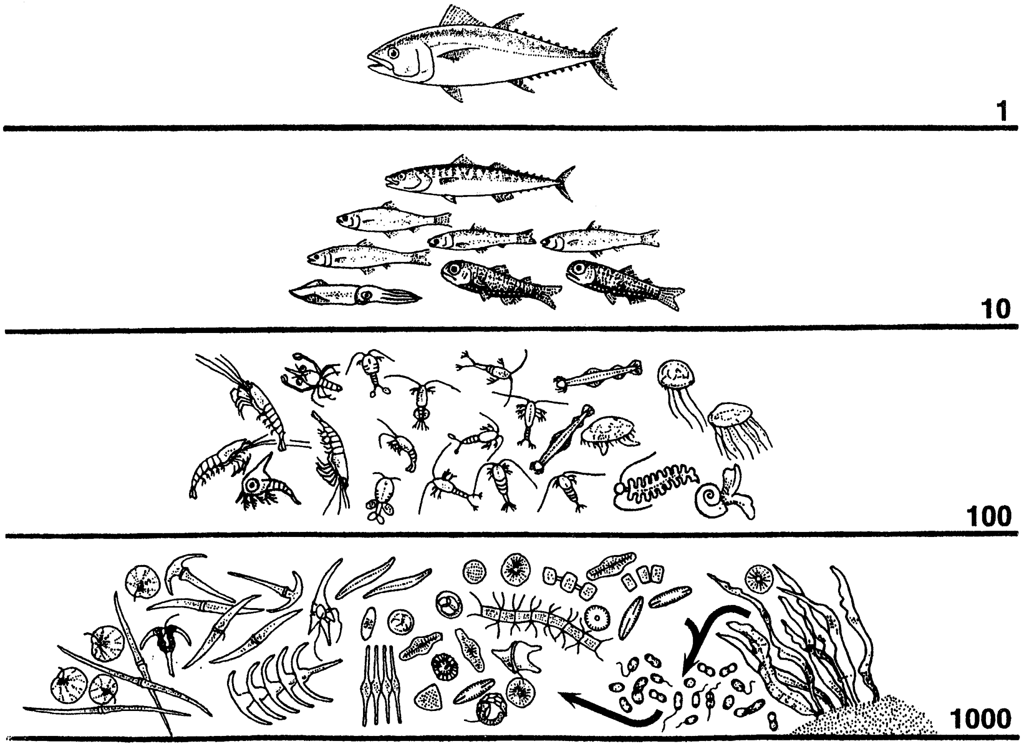

Fig. 5. Pyramid of energy in the marine ecosystem, based on the marine food web with the grazing food chains and the detritus food chains

variable factors of the marine ecosystem. This characteristic has a favourable function for the constant supply of biomass to the second trophic level of the ecological pyramid, by backing up the unstable supply of phytoplankton, and eventually contributing to the stability of marine ecosystem.

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「海洋食物網における腐食連鎖の卓越性に関する主導的研究」

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要　旨：生物圏を構成しているすべての生態系では，被食者と捕食者との関係における繋がりは，生態系の機能から生きている生物を直接に食う連鎖である生食連鎖と，死骸または生体の破片や排出物を食う連鎖である腐食連鎖によって構成されている．

この両者の関係において，著者(SEKI, 1964; 1965; 1966; SEKI *et al.*, 1968)は，「海洋においては生産層でも分解層でも腐食連鎖が卓越して，その結果として海洋全体としても腐食連鎖が卓越すること」を先駆的に実験生態学的に実証した．その後，多くの海洋生態学者が種々な角度から研究を重ねて，大同小異の結果を得ている．それらの研究結果の共通した結論から，海洋食物網における腐食連鎖の卓越性は，現在では海洋生態学上の常識となっている．

このように「海洋において腐食連鎖が卓越すること」が海洋生態系の安定性をもたらすことを，(1)食物網を構成する海洋動物の食性と(2)全海洋の生物群集におけるエネルギー流　の視点から，明らかにしてきた主導的な研究を簡潔に総説する．

前者の視点に関しては，多くの海洋動物種が食物連鎖の特定な栄養段階に分別されることなく，環境変化に応じて食物種を自在に変更することによって，複雑な海洋生態系構成生物群にあっても個体群サイズを安定させていることから，解明されるに至っている．

後者の視点に関しては，全海洋における基礎生産に利用可能な太陽エネルギー量や，全海洋において観測された基礎生産量，そしてFAOなどの全海洋における水産統計から生態学的に算定される基礎生産量を突き合わせることによって，明白な現象と認識されている．

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資　料

黒潮流域の沿岸潮位および年周潮スペクトルの長期変動

中　村　重　久*

Interannual variations of coastal sea levels and annual tides spectra neighbor Kuroshio flow

Shigehisa NAKAMURA*

Abstract : This work concerns the interannal variations of the sea levels on the coast facing an ocean. Interannual variations of the sea levels and of annual tides on the coast are studied referring to amplitude spectra reduced after applying fast Fourier transform (FFT) method. Special reference is that in an local area covering Kuroshio flow off the south of the Honshu in the Japanese Islands, and in an specific area just as a part of seismic and tectonic active zone. Specific pattern of the apmlitude spectra of the annual tides at the local tide stations are analyzed and studied.

Key words : *monthly mean sea level, annual tides, internal variations, Kuroshio*

1. 緒　言

外洋に面した沿岸域における潮位変動のうち，とくに，年周潮を中心とした振幅スペクトルの長期的変動を研究した。ここでは，とくに，太平洋北西部の日本列島南岸周辺を対象とする。この対象水域には黒潮が流れており，さらに日本列島はユーラシア大陸の東縁境界に近く，環太平洋地震帯の一部になっていて，沿岸潮位は黒潮の変動や地殻の変動などに影響を受けているものと考えられる。このために，たとえば潮位の平均的傾向を見ることによって，地球の温暖化やそれに関連した海水位変動がただちに解るというようには考えられない。ここでは，紀伊半島にあるいくつかの検潮所の記録から，年周潮スペクトルを求め，その特性を調べ，黒潮変動やその他の変動現象との関連について明らかにしようと試みた。

2. 潮位スペクトルの概観

海水位の変動は古くから知られており，その原因としての外力の主要なものについては多くの研究例が見られる。とくに天文潮については，古典力学に立脚した分潮成分が知られている（たとえば，小倉，1937; 中野，1939; DIETRICH, 1957; DUVANIN, 1960)。

沿岸域の高度利用と関連して，日周潮および半日周潮

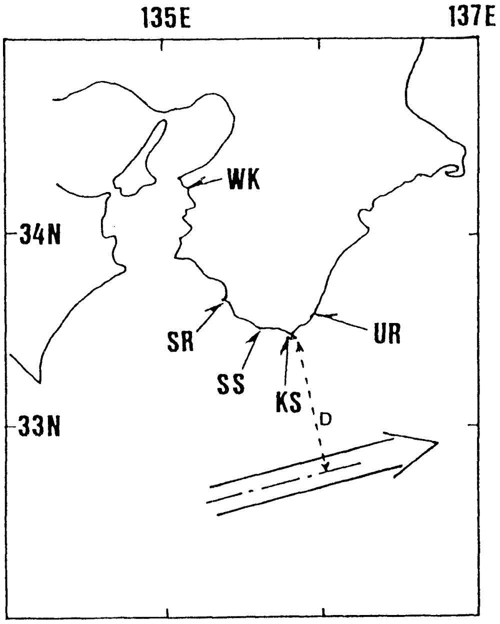

Fig. 1　Coastal configulation of the interested area where notations of the tide station are WK for Wakayama, SR for Shirahama, SS for Susami, KS for Kushimoto and UR for Uragami and D for distance from the coast to the Kuroshio flow axis off Kushimoto.

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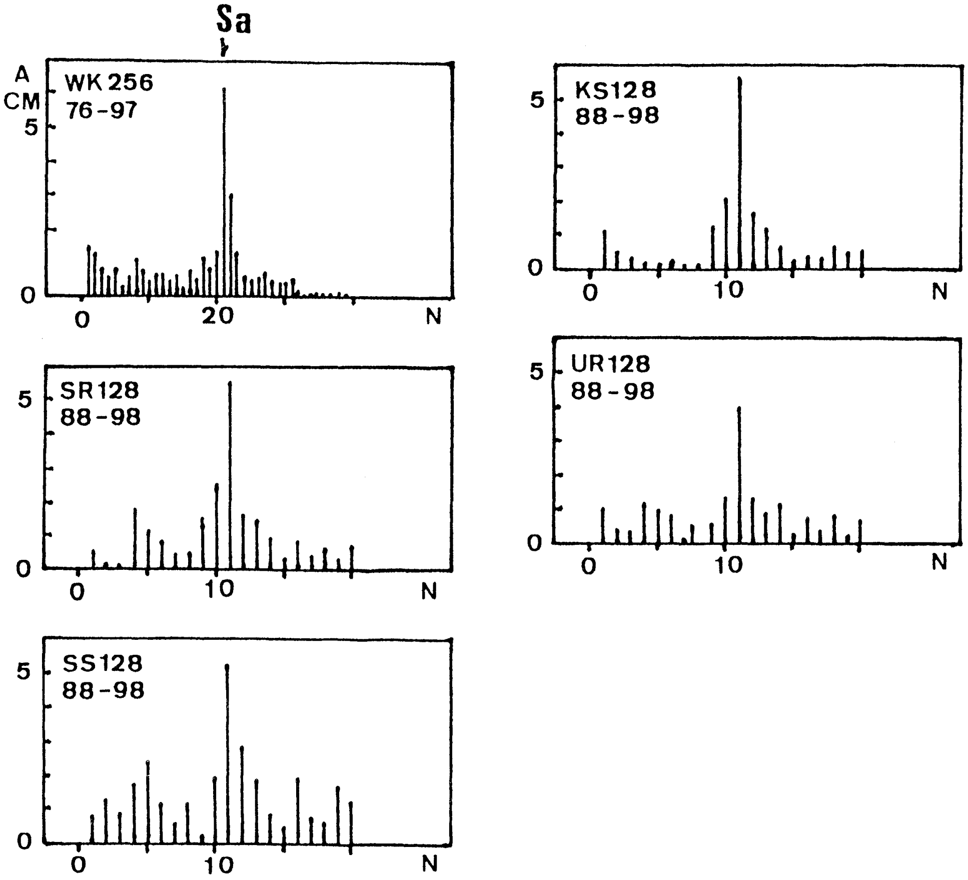

Fig. 2. Amplitude spectra at tide stations as diagrams of the spectral amplitude component (*A*) and the numeral order (*N*) of the spectral component (frequency $f=N/M$) in which the frequency band of the annual component is noted by *Sa*, at Wakayama ($M=256$ during 1976 and 1997), and at Shirahama, Susami, Kushimoto and Uragami ($M=128$ duruing 1988 and 1998).

についての研究例はこれまでに非常に多く，ここにそのすべてを記すことはできない。これに対して，年周潮やさらに長い周期の海水位変動について述べた例はごく限られている。Maximov（1970）は，海水位の変動が一年以上の長い周期成分や，非周期成分についての研究成果を記している。Lambeck（1980）は，地球の回転運動と関連した海洋の変動について述べている。Hosoyama *et al.*（1976）は，地球の極潮汐のアドミッタンスについての研究成果を発表し，また黒潮とZ項との関連についての研究例としてはNaito（1974）の例がある。

海水位変動の解析の歴史を顧みるとともに，スペクトル解析の手法を潮位変動の問題にはじめて導入したのは，Munkと彼の研究グループである（たとえば，Munk and Cartwright, 1966）。

しかし，年周潮の変動現象についてはあまり顧みられていなかった。著者の知る限りでは，いくつかの検潮記録について，年周潮スペクトルの長期変動やそのスペクトルパターンの研究の若干例があるにすぎない（たとえば，中村，1988：Nakamura, 1997, 1998, 1999, 2000）。

Cartwright（1988）は，人工衛星による潮位計測およびその解析について研究し，半月周期成分についての検討結果を報告している。人工衛星SEASATのデータは短期間ではあったが，Cartwright and Alcock（1981）によって，太平洋北東部の海面高度および海面勾配の精度の研究に利用されている。このSEASATのあと，GEOSATが地球上の高度計測の役割をひきついだ。そのあと，2000年現在までのところ計測精度は1 cm（未確認情報）となっていると言われるが，海面高度の長期にわたる時間変動の解析研究には，これからさらにデータの蓄積を継続することが必要である。また，人工衛星データの利用にあたっては，地上および海上に

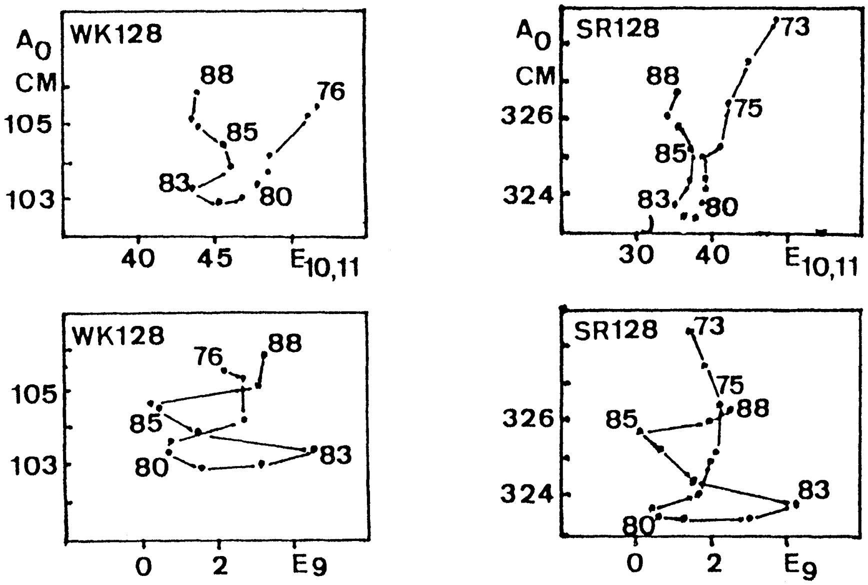

Fig. 3. Mean sea level (A_0) and energies related to the annual tides ($E_{10,11}=A_{10}^2$, and $E_9=A_9^2$), at Wakayama for the period of 1976 to 1988 and at Shirahama for the period of 1973 to 1988, where the notations A_0, A_9, A_{10} and A_{11} are for the zeroth, nineth, tenth and eleventh order of spectral components in Fig. 2.

における直接測定を基準とした補正や，その他の誤差要因にたいする補正が必要である。

長期間にわたる海水位変動の記録は，たとえば，日本では気象庁，海上保安庁，国土地理院のほか，農林水産省，その他の関連機関によって得られている。そのような記録を利用して，海洋の諸問題についての研究例もこれまでに多いが，そのなかで数十年以上の長期間にわたる潮位変動の研究例は，海水位変動予測の問題に関連して重要と考えられるが，著者の知るところではごく少数である。ごく最近の例として，Nakamura (1988, 1990, 1994a, b, 1996a, b, 1997, 1998, 1999, 2000) は太平洋北西部の日本列島南岸での潮位変動の研究をしている。

3. 年周潮スペクトル

ここでは，外洋に面した沿岸域における年周潮スペクトルの特性を具体的に把握するために，とくに太平洋北西部の日本列島の南岸で，その沖合に黒潮がみられるような地理的条件を満たす地域を対象とする。この地域は，Fig. 1に示されている。本文では，和歌山，白浜，串本，浦神（以上，気象庁所管）および周参見（農林水産省所管）の核検潮所における検潮記録より求められた月平均潮位のデータを用いる。

スペクトル解析にあたって，FFT (Fast Fourier Transform) 法を用い，振幅スペクトルを求めることとする。ここで，和歌山，白浜，周参見，串本，浦神について，得られたスペクトルは Fig. 2 に示すとおりである。和歌山については，1976-1997年の 256 ケ月のデータを用いた。その他の 4 検潮所については，1988-1998年の 128 ケ月のデータを用いた。この Fig. 2 によれば，いずれの検潮所でも，年周潮成分Saの振幅がとくに顕著である。ここで，スペクトルのパターンに着目すると，周参見ではその他の検潮所の比較して，年周潮Saのサイドローブの成分の振幅が大きいことである。これは，周参見の地理的立地条件が黒潮流軸変動の影響を強く受けていることを示すものと推察されるが，現時点ではその確証があると断定するまでには至っていない。

4. 平均海水位と年周潮のエネルギー

ここで，とくに和歌山と白浜とについて，それぞれ128ケ月のデータによる振幅スペクトルを求め，その第0次成分（A_0）としての平均海水位と，年周潮Saに関わると考えられる第10，11次成分（A_{10}, A_{11}），および第9次成分（A_9）に着目する。

潮位変動がいろいろの周期成分の線形的な合成によって現れているものとすると，記録をスペクトル解析した結果としての振幅スペクトルの成分が，潮汐現象の力学的に意味のある振幅成分ということになる。このとき，便宜的に，年周潮のエネルギーが，Fig. 2 の Sa およびその周辺の成分の平方の和に比例すると見なして評価できることになる。たとえば，A_0 と $E_{10,11}=A_{10}^2+A_{11}^2$ と

の関係は，Fig. 3の上段のようになり，パラメータとして時間をとると，この関係は時間的に変動しており，しかも，和歌山と白浜とでは，その変動パターンには共通したところがあるようにみられる。

また，A_0と$E_9=A_9^2$との関係は，Fig. 3の下段のようになり，パラメータとしての時間にたいして，変動パターンには，上段とは異なるが，和歌山と白浜とでは共通したところがあるようである。

このFig. 3に見られる関係の時間的変動パターンは，いずれも，128ケ月のデータのスペクトル解析によって得られたもので，言わば，約11年（128ケ月）についての平均海水位の年次的変化を示していることになる。ここで，太陽活動に約11年の周期があることを考慮したとして，Fig. 3の年次的変化が，この太陽活動の変動と同期しているならば，この変化の主要因は簡単に判断できることになる。しかし，Fig. 3の変化のパターンは複雑であって，その他にも多くの外的要因が作用していることを示唆しているものと考えられる。だが，その要因が何であるかを判断するに足るものが，いまのところ可能性として考えられているに過ぎない。推測として，主要因には海洋の問題としての黒潮変動やエルニーニョなどのほか，1995年の兵庫県南部の地震発生に関連した測地学的な問題としての地殻変動などが含まれていると言っても間違いではないであろう。

5. 結　言

年周潮スペクトルの長期的変動をFFT法によって解析し，その特性について研究した。ここでは，とくに黒潮変動の影響が認められる太平洋北西部の日本列島南岸周辺の検潮所，和歌山，白浜，周参見，串本，浦神を対象として，そこでの月平均海水位のデータを利用した。それぞれの検潮所における振幅スペクトルの特徴を示すとともに，スペクトルパターンの検討結果から，とくに和歌山および白浜における，11年平均海水位の変動と年周潮周期成分に関連したスペクトル成分のエネルギーと共通の対応関連を論じた。この対応関係が，その他のどのような力学的要因によって支配されているかは，これからの研究によって解明すべきことである。

なお，本文は著者が京都大学における研究課題を継続して得られた成果の一部であることを記して，関係各位のご理解とご協力に心から感謝の意をあらわす。

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資　料

平成12年度　日仏海洋学会学術研究発表会　講演要旨

平成12年６月18日(日)　日仏会館会議室

(１) 低塩分及び高塩分環境に生息する細菌と古細菌から構成される天然微生物群集が示すGSI(グラム染色指標)……○才田春夫(筑波大)・亀倉正博(野田産研)・Wael S. M. El-Sayed・Mohamed Abu-Shady(Ain Shams大)・安部征雄・山口智治(筑波大)・Yang Peiling(China Agriculture大)・前川孝昭・關　文威(筑波大)

異なる塩分環境に生息する天然微生物群集が示すグラム染色指標(GSI)に関する研究を行った。研究対象は，河川や海洋を含む，極端に塩分環境の異なる複数の地域から採取した塩結晶及び現場水に生息する好塩古細菌や細菌を含む天然微生物群集である。これら現場の内，エジプトのOyon Moussa poolと中国のAidingkol–Hu塩湖は塩分が高度に集積した環境である。又，伊豆半島の下田湾に流入する稲生沢川下流から黒潮反流にかけての４地点は緩やかな塩分勾配を形成する環境である。エジプト及び中国から分離した高度好塩古細菌は同定とグラム染色を行い，画像解析装置を応用したグラム染色評価法により解析を行った。

分離した好塩古細菌のうち，種まで同定出来た*Halobacterium salinarum*の*GSI*を高度好塩性古細菌の代表として，典型的なグラム陰性細菌である*Escherichia coli*と典型的なグラム陽性細菌である*Bacillus subtilis*のGSIと比較して，高度好塩古細菌のGSIが細菌のそれと特異的に異なる形状を示すことを確認した。又，*H. salinarum*のGSIを他の分離古細菌やAidingkol–Hu塩湖内天然微生物群集のGSIとの比較も行った。その結果，高度好塩古細菌が優占する中国塩湖，Aidingkol–Hu Lake，の微生物群集が*H. salinarum*に似たGSI形状を示すことを明らかにした。又，高度好塩古細菌のGSIが細菌と特異的に異なる形状を示すことが判明した。従って，GSI法(Saida *et al.* 1998 and 2000)は高度好塩古細菌を含む水圏微生物群集解析にも有効であると言える。

(２) 霞ヶ浦における植物プランクトンに及ぼす生簀養鯉の影響……○東　陽介・中根　剛(筑波大)・熊丸敦郎(茨城県内水試)

霞ヶ浦において１．養鯉生簀から排出される物質が周辺水環境にどの程度拡がるか，２．それらの物質が生簀周辺に生息する植物プランクトンの生産力にどのような影響を与えるかを水平方向の分布に注目して研究した。毎月比較的水の動きの少ない午前中に生簀直上を０mとして流れにまかせて船を流し，25m間隔で200mまで水深0.5mから採水した。水温等の現場環境要因の測定を行い，採水した水は直ちにワットマンGF/Cフィルターでろ過後，各種栄養塩等の水質分析(Apha *el al*, 1992)，優占植物プランクトン種の同定(Mizuno, 1971)を行った。また各地点で明瓶暗瓶法を用い，一次生産量の測定を行った。

夏季から秋季にかけて，生簀から大量のアンモニアの放出がみられ，生簀直上を頂点とするアンモニア濃度傾斜の形成が見られた。逆に溶存酸素量は生簀直上で最も低くなり，離れるに従って増加した。一方でクロロフィルα量で指標した植物プランクトン量は生簀よりもやや離れた部分にピークが見られた。アンモニアの濃度が高いほど，植物プランクトンによる酸素発生量を指標とした一次生産量が高く，生簀からのアンモニアの放出による一次生産の促進が見られた。このアンモニアの広がりは，採水地点の距離を流速で割ることにより標準化した標準距離の値で表すとほぼ１～２m $\mathrm{sec^{-1}}$の範囲(流速が0.05m $\mathrm{sec^{-1}}$のとき20～40mまで広がることを示す)であった。酸素発生量あたりのクロロフィルα合成量から換算した生産効率をみると，春季から夏季に向けて藍色細菌(*Oscillatoria*)が優占する時期は生産効率が上がるが，ヘテロトフィックな活動が高くなる夏季後半から秋季にかけて生産効率は下がり，珪藻(*Melosira*)の優占する冬季にはさらに低下した。

(３) 植物プランクトン群集の蛍光分光法による種類構成の評価……○松沢勇志・桑原朋彦・關　文威(筑波大)

水界現場での測光学的な手法を用いて植物プランクトン群集の化学組成を測定して種分類を行うための基礎知識を

得るために，海産植物プランクトン培養細胞の蛍光測定を行った。標準種として，珪藻類は*Skeletonema costatum* を，ハプト藻種は*Emiliania huxleyi* を，緑藻類は*Chlorella desicata* を，ペラゴ藻種は*Sarcinocrysis marina* を試料として用いた。まず，メタノールにより抽出処理した色素について蛍光特性を三次元的に解析した。その結果，クロロフィル$a \cdot b$をもつ緑藻類と，$a \cdot c$をもつ黄色藻類では，蛍光特性が異なることが判明した。これらの相違を明確にするために単離・分取した色素について同様の蛍光測定を行ったが，蛍光特性の違いはクロロフィル類によるものであり，キサントフィル類の違いによる蛍光特性の相違はみられなかった。そこで，キサントフィル類などに取得された光エネルギーがクロロフィルaへ伝達され，放出される赤色蛍光から，蛍光特性の違いを検討するために，藻生体の放出する蛍光の測定を行った。ここでは，fucoxanthin をもつ珪藻，19'-hexanoyloxyfucoxanthin をもつハプト藻，および 19'-butanoyloxyfucoxanthin をもつペラゴ藻について，放出蛍光波長を 680 nm（赤色蛍光）に固定して励起波長を測定した。その結果，500～550 nm 付近の波長特性に相違が見られたので，この付近の励起波長を詳細に解析すれば，各植物群に特異的なキサントフィルに由来する蛍光特性が明らかになる可能性が示唆された。

以上の結果は以下のように要約される。

（1）藻類の抽出色素については，クロロフィル類は藻類の種類によって波長・強度が異なり，キサントフィル類は種類によらず蛍光を発しないことを確認した。

（2）藻類の生体については，クロロフィル類およびフコキサンチン類より伝達されるエネルギーに対応する励起波長の大要を確認した。特に500～550nmの波長はフコキサンチンを代表としたキサントフィルの吸収領域の裾野に相当する部分であり，キサントフィルはクロロフィル類の吸収しない波長領域の光を吸収・利用していることが判明した。

（4）断続光の明暗周期変化と植物プランクトンの増殖量との関係……○渡部　武・山崎七重・荒川久幸・森永　勤（東水大）

ノリ養殖では風の弱い年より連吹期の長い年に収穫量が増大することが言われている。この現象では溶存ガスの交換や栄養塩の取り込みに効果があるためではないかと指摘されている。しかし著者等はこの原因として，太陽透過光の短時間変動，すなわち波による海中での光の短時間周期の変動がノリの生長へ影響を及ぼしているのではないかと考えた。そこで本研究では，連続光および断続光を植物プランクトンに照射して増殖量の比較を行い，断続光による光刺激の効果を明らかにすることを目的とした。

実験は暗室内にて行った。光照射装置は光源（白熱電球：100 V，200 W），遮光装置および恒温水槽（20℃）で構成されている。植物プランクトンには*Isochrysis galbana* を用いた。培養液（1.2×10^5cells/ℓ）を恒温水槽内に設置した 1 ℓ ビーカに満たし，連続光および断続光（断続周期：0.2，2，20 cps）を照射して培養を開始した。試水はスターラで撹拌し，試水の表面の照度は 40 μmol/m^2/sec とした。試水より10～20 mℓ 採取し，プランクトンの数及びクロロフィルa濃度について，コールタ・カウンタ（マルチサイザーII）及び蛍光光度計（Turner 10AU）をそれぞれ用いて測定した。

結果は以下のように要約される。

1）プランクトンの体積平均粒径は，実験開始時 4.51 μm であった。連続光と 0.2 cps の遮断光では，11日目 4.60，4.55 μm であり，2及び 20 cps では 4.30，4.24 μm とやや小さかった。

2）プランクトンの体積比（実験開始時の体積を1）は，連続光では11日目で初日の約20倍まで増加した。これに対し，0.2 及び 2 cps の断続光での体積比は連続光のそれぞれ 43 % 及び 33 % となり，20 cpsではほとんど増加しなかった。

3）クロロフィルa濃度は，連続光では総照射量 17 mol/m^2 で 312 μg/Lであったのに対し，0.2，2 cps ではそれぞれ連続光の 1.85 倍，1.15 倍となった。明暗周期の遅いものほどクロロフィルa濃度の高くなる傾向が見られた。

4）クロロフィルa濃度（y）と体積（x）の回帰直線は 0.2 cps：$y=1.2x-34$，2 cps：$y=1.2x=32$，20 cps：$y=0.99x-22$，連続光：$y=0.66x+18$であった。

以上のことから，断続光の照射は，細胞内の葉緑体のサイズに影響を及ぼしていることが示唆された。

（5）水柱内での溶存メタン酸化—東京湾，霞ヶ浦，野尻湖を例にして—……○内海真生（筑波大・農工）・野尻幸宏（国立環境研）中村岳史（東水大）

メタンは温室効果ガスの1つであり二酸化炭素につぐ温室効果寄与率を持っている。メタンの自然発生源として最も大きな割合を占めるものに湿原などの水域がある。水域から大気へのメタン放出量は，水柱内でのメタン酸化によ

り大きく影響を受ける。現在，温暖化現象解明のため世界中の水域でメタン放出量に関する研究が行われているが，水柱のメタン酸化まで含めた研究はほとんどない。ここでは，浅い富栄養水域である東京湾並びに霞ヶ浦，中栄養の復循環湖である野尻湖水柱の溶存メタン酸化について行った研究を報告する。溶存メタン酸化速度の測定には，従来行われていた$^{14}CH_4$添加法ではなく，現場で直接作業が可能であるバイアルビンインキュベーション法を用いた。この方法では，サンプル水を採水後，直ちに10数本のガラスバイアルビンに分取，密封して，現場水温，暗所条件でインキュベートを行う。その後，一定時間毎に2本のバイアルビンに塩化第二水銀溶液を添加してメタン酸化活性を止め，ビン内の溶存メタン濃度を自動気体濃縮装置付きメタン分析計で測定し，ビン内溶存メタン濃度の経時片かからメタン酸化速度を求める。本方法を用いることで，現場での溶存メタン酸化速度をより正確に測定することが可能になった。富栄養化水域である東京湾において6月並びに8月に溶存メタン酸化速度の測定を行った結果，水柱内でのメタン酸化は観察されなかった。浅い富栄養化湖沼である霞ヶ浦において，1991年から5年間継続的に溶存メタン酸化速度を測定したところ，水柱内溶存メタン酸化速度に明瞭な季節変動(冬季から春季の低速度期，夏季から秋季にかけての高速度期)があることが明らかとなった。また，湖水中メタンの滞留時間が秋季には半日以下で霞ヶ浦湖水の滞留時間(220日)と比べ非常に短い時間であることや，水柱内溶存メタンのうち年平均74%がメタン酸化により消失していることが判明した。野尻湖では，冬季湖水循環器に一時的に湖水全層の溶存メタン酸化速度が高まった。この冬季湖水循環期間中においては湖水溶存メタンの9割以上が酸化により消失することが判明した。その他の既設では酸素躍層近傍で比較的高い溶存メタン酸化速度が観察された以外，低い酸化速度であった。

（6）大平洋流動解析に基づく液化CO_2海洋隔離の可能性の検討……長谷川一幸・和田　明(日大生産工)・高野憲治(コロンビア大学)

近年，二酸化炭素の増加による地球温暖化が懸念されている。大気中の二酸化炭素濃度の急激な上昇に対して海面のみからの二酸化炭素吸収によってそれを充分に緩和するということは極めて難しい。そこで，地上の排出源から分離改修し貯蔵された二酸化炭素を，海洋の中深層(深度約1,000 m以深)に放流することにより，本来海洋の持つ潜在的な人酸化炭素吸収能力を人工的に補い，その結果として大気への二酸化炭素の蓄積を抑制することを狙いとする技術が注目されている。

そこで，本研究ではデータ同化手法を用いて大平洋上の流れ場の算定を行い，この中に液化二酸化炭素に見立てた粒子を投入する。そして，この粒子の軌跡を追跡することによって液化二酸化炭素の海洋投棄の可能性を検討する。ここでデータ同化手法とは，観測データがデータ同化項を通して連続的にモデルに同化される手法であり，計算値が観測値からずれると同化項は大きくなり，計算値を観測値に戻すように働く。これにより，局所的に異常な流れが発生したときにも，現実に近い流れを再現することができる。その結果，計算で算出される流れは物理的にも観測値との比較に対しても満足するものとなる。また，計算で使用されたデータはNASAのGoddard Space Flight Center (GSFC)から提供を受けた海上風データ，JODC所蔵の1906～1988年の約80年間各層観測水温・塩分データである。流れ場の計算結果は，道田(1995)が算出した漂流ブイ軌跡から求めた表面海流の平均場結果とほぼ一致した。また，赤道付近において海流の境界の区分が明確に再現されなかったものの，主な大平洋上の海流である黒潮，南北赤道海流，赤道反流・何曲周極流等が再現された。特に親潮，インドネシア通過流，亜熱帯反流などの比較的流量が少ないとされる流れの再現性も良好であった。この流れ場の中に液化二酸化炭素に見立てた粒子を投入し，その軌跡を調べたところ，液化二酸化炭素の海洋隔離実験が予定されているハワイ・コナ市沖合では，水深2000 m以深で投入した粒子は表層には達しないことが判明し海洋投棄は2000 m以深が望ましいことが示唆された。しかし，粒子の挙動は特に表層で海面フラックスの影響を受けることが判明し，これらの精度向上が期待される。

（7）乱流観測装置の開発について……山崎秀勝(東水大)

海洋における乱流を計測することは，すでに1950年代の後半から試みられ，比較的長い計測の歴史をもっている。コロモゴロフの慣性量小領域の存在について初めて検証したのも，海洋の乱流観測であった。しかしながら，乱流を観測するためには，現在でも高度の技術を必要とし，ひとにぎりの研究者らによって海洋の乱流研究は支えられている。そこで広く一般のユーザーにも使用する事の出来る乱流観測装置の開発が必要であると考えた。さらに，乱流ばかりでなく生物生産の指標となるクロロフィルや濁度も微細なスケールで観測できるように計画をたて，アレック電子の技術協力のもと乱流観測装置(Turbulence–Microstructure Acquisition Profiler, TurbMAP)の開発を続けている。Turb MAP開発の第一段階を終了し，湖，沿岸域および公海域において観測装置のテストを行った。TurbMAPは自由落下型の円筒形をした，約2メートルのものである。装置の先端には乱流の流速成分を計測するシェアープロー

ブ，高解像度の温度計FP07，クロロフィルと濁度を計測する光学プローブ，安定度の高い白金温度計，電気伝統度計及び水圧計を搭載している。さらに装置内部の先端部に近いところに3軸の加速度計を組み込んである。それぞれのプローブは256 Hzの速度でデータを，内部のメモリーカードに記憶することができる。観測装置は，水中を約50 cm/sで自由落下するので，ほぼ2 mm間隔でデータを採集している。講演では，この観測装置から得られたデータを紹介し，クロロフィルプローブから得られた新知見についても，これまでの研究成果などとの関わりとともに発表した。

(8) Microscale processes in the ocean: why are they so important for ecosystem functioning? ……Laurent Seuront (Tokyo Univ. Fish.)

Turbulence has widely been regarded as being a homogeneous process. Turbulence effects on ecosystem fluxes have thus been estimated using mean values of turbulent kinetic energy dissipation rates. However, turbulent processes are highly intermittent, a framework inconsistent with an average representation of turbulence. The intermittent nature of microscale turbulence, modeled in the speciffic theoretical framework related to multifractals, leads to (i) an increase in the rate of nutrient fluxes around non-motile phytoplankton cells (6–62%), (ii) a decrease in the physical coagulation of phytoplankton cells (25–48%)and in the subsequent phytoplankton aggregate volumes (22–41%), and (iii) a decrease of the turbulence contribution to predator-prey encounter rates (25–50%).

(9) Numerical Simulation of Density Current in Tokyo Bay……Ivonne M. Radjawane, Y. Kitade and M. Matsuyama (Tokyo Univ. Fish.)

A numerical experiment was conducted to study the circulation of the low-salinity water in Tokyo Bay by a three-dimensional baroclinic model (POM). The fresh water discharged from the rivers was mixed round the sea surface water of the bay around the mouth of the rivers and the formation of low-salinity water was confirmed there. The main rivers are located at the western coast of the bay and at bay head, i. e., Edo River, Ara River, Tama River and Tsurumi River. The total volume transport from the rivers to the bay is about 130 m^3/s in summer.

The experiment was made under the initial and boundary condition for the summer of 1995. The salinity water slowly runs toward the bay mouth along the western coast and the characteristics of its behavior is similar to the density current in the baroclinic fiedl in rotation gluid. The salinity distributions obtained by the numerical experiments were compared with the observational one by Japan Hydrographic Agenecy. The results show that the numerical model is possible to apply to the behavior and structure of the low salinity water in the bay. The detailed results will appear in this journal.

(10) Variability of Low Saline Water flowed out from Tokyo Bay into Sagami Bay……I Wayan Nurjaya, Masaji Matsuyama and Yujiro Kitade (Tokyo Univ. Fish.)

In coastal water of the world, low saline water (LSW) discharged from rivers are well known to be often affected by a rotation of the earth, i.e., Coriolis' force. LSW behaves as a density current in a rotating fluid, that is, LSW tends to flow with the narrow width along the coast.

We have examined to verify the structure and behavior of LSW near the mouth of Tokyo Bay by the detailed CTD observations. In addition, dynamics of LSW is also investigated through the distribution of salinity, temperature, density and current. The 17 observations were made along two observational lines, southward and westward lines from the tip of Miura Peninsula, located at the mouth of Tokyo Bay, from 1997 to 2000.

The observational results are as follows.

(1) Every observation indicates the coastal trapping structure of LSW along Miura Peninsula.
(2) The distributions of LSW are variable, and do not show the remarked seasonal variation except winter when the river discharged water is extremely small.
(3) The width of LSW is estimated 3–6 km by the salinity distribution. This width almost agrees with the

internal radius of deformation, i.e., the width of the density current obtained by theoretical result.

(4) The current speed estimated by the thermal wind relation is 5–20 cm/s in the southern line.

(5) The fresh water volume is also estimated by the fraction of salinity and current speed by the thermal wind relatin. The volume is range between 113 and 867 m^3/s, and is tha same order of the river volume transport into Tokyo Bay.

(11) 衛星赤外画像パーソナルコンピュータ受信からみた黒潮フロントの力学的特性……中村重久(和歌山県田辺市)

人工衛星によって得られた赤外画像を利用すれば，海面水温分布のモニタリングが可能である。ここでは，とくに，NOAA人工衛星から送信されている自動図化変換(APT)システムの電波信号を，受信点のクロスバーアンテナの上空を通過する人工衛星から，直接，パーソナルコンピュータによって，実時間(リアルタイム)で，赤外画像として受信したものを利用した結果の要点について述べた。また，具体的な問題としての理解のために，利用した画像は，日本列島の黒潮流域を含む海域とした。このようにして得られた画像のピクセルは，およそ4km平方であり，AVHRR(超高分解能レーダ)による画像のおよそ1km平方に比較すると，画像としては粗いが，リアルタイムで画像が得られるという特徴がある。日本の漁船には，この受信装置を，実際に，漁場追跡に利用している例もある。ここでは，外洋の変動と沿岸の変動との相互関係をもとめるために，この受信装置を用いて，解析研究した。外洋水と沿岸水との出合ったところを，ここでは，黒潮フロントとして見ることにした。黒潮が，地衡流的であるとすれば，この黒潮フロントに平行して，黒潮流軸があるはずである。この流軸の変動，とくに，蛇行については，日本の海洋学者をはじめ，世界中の学者がこれまで，長い間にわたり研究してきた。黒潮流域の直接観測の記録は，長期間にわたって得られているが，同時観測記録としては，衛星データを利用するほうが好都合である。最近の理論的研究を参考にすると，線形的なの黒潮フロントの時空構造の変動が，衛星赤外画像にも認められる。さらに，摂動法によって得られた弱い非線形過程と認められる変動もある。陸だなや海底地形を考慮して，漸近法による積分によって得られる強い非線形過程は，黒潮フロントの巻き込みに対応した黒潮流軸の大蛇行に認められると考えられる。さらに複雑な黒潮フロントの変動の力学的理解には，今後の研究が必要である。

(12) アラビア海，ベンガル海底扇状地，およびメキシコ湾で採取されたドリルコアの鉱物・地球化学的研究(予報)……青木三郎(東洋大・経済)

アラビア海(PDO117)，ベンガル海底扇状地(PDO116)，メキシコ湾(DSDP96)で採取されたドリルコアサンプルの粘土鉱物と化学組成について，XRD，ATEM，XFRで調べた。アラビア海の7本のコア中の粘土鉱物組成は3グループに分類される。第一はパリゴルスカイトがコア全体に分布するグループ，第二はパリゴルがコアの下部に集中するグループ，そして第三はコアに散在するグループである。各コアはいずれも第三紀中新世に達し，これらの結果から，1000万年以降のアラビア海周辺の気候変動史を読み取ることが可能と思われる。堆積物の化学組成分析では，K/Al，Fe/Al，C/Al, Ti/Alで示される珪酸塩鉱物インデックスとP/Alの有機物インデックス，Sr/Caの石灰質生物生産活動インデックスは，Oman MarginとOwen Ridgeでは有意義な結果が得られた。

ベンガル海底扇状地の3本のドリルコアはいずれも，中新世下部に達し1800万年以降の堆積史を検討するうえでの格好のサンプルである。粘土鉱物組成から，ヒマラヤの隆起運動との関連性を検討し，一定の結果をえた。すなわち，クロライトとイライトは隆起運動の活発化と，スメクタイトとカオリナイトは鎮静化に対応することを指摘した。また，スメクタイトの供給源をインドのデカン高原だけでなく，海嶺玄武岩からの由来も指摘した。地球化学的データでは，P/Al，Sr/Ca, Cr/Alは，各層準に対応した変動を示し，砕屑性鉱物と有機物，石灰質生物生産量に有意な相関性があることを示した。

メキシコ湾の3本のコア分析では，粘土鉱物組成に有意な結果が得られた。すなわち，スメクタイトが卓越するコアと層準によって大きく変動するタイプに分かれる。コアはいずれも第四紀，200万年以降のサンプルで湾内の3地点での鉱物組成の大きな差違は，周辺の陸上環境の相違よりも，堆積・運搬環境の変動に起因するものと考えられる。スメクタイトの化学組成は，Al–Fe(Fe–Al)バイデライトのみならず，3–8面体のサポナイトも含まれ，多様な供給源の可能性を示した。一方，クロライトはいずれも3–8面体のFe–Mgタイプで他の海底堆積物中のそれと変わらない。地球化学的データでは，200万年以降，大きな変動を示す結果は得られていない。

(13) 新しい海洋療法―深海療法(Abyssothérapie)とめかぶ療法(Sporophyllthérapie)について……野村　正(日本海洋療法研究会)

最近の世界の海洋療法(タラソテラピー)の動向を述べたのち，我が国独自のタラソテラピーとして考えられる次の療法を提唱する。

1．深海療法

1998年，富山県滑川市にいわゆる海洋深層水(DSW)を用いる療法施設“タラソピア”がオープンした。これは世界初のタラソテラピーセンターである。海洋学用語上本来の深層水ではないが，通称としてAbyssothérapieと訳した。学問上問題であるが，“環境ホルモン”の場合から考えても便利であろう。

Badelone医博の定義が示すようにタラソテラピーは海水だけではない。しかし海水は基本となるものであるから，今後のDSWの利用の発展が期待される。世界的に海洋の汚染を止めることができない時期に，清浄性，ミネラル特性の点でDSWは安心して利用できるメリットをもち，他方海の清浄性の意義の再確認の上からも大切である。医療的効用の証明が不足であり，果たしてタラソテラピーによい海水として遠洋表層水や海中林水(marine forest seawater)などにくらべてDSWがベストであるか不明であるが。

2．めかぶ療法

めかぶ(芽株，胞子葉，成実葉，ミミ，めひび，まなかし)はワカメの胞子を形成する特別な葉状部であるが種々の生理活性物質を含む。広義の海藻療法の中にこのめかぶ療法は含められるが，タラソテラピーにはまだ利用されることが少ないので命名した。めかぶの成分上の特性として次の諸点があげられる。

(1) ミネラル(Li, Fe, I, K)………ホルモンの調整
(2) アルギン酸…………………………膜保護，有害金属除去，コレステロール低下作用
(3) フコイダン(U-アポイダン)……抗腫瘍
(4) EPA………………………………老化防止など
(5) フコステロール……………………血栓予防と溶解作用
(6) ナイアシン…………………………坑ペラグラ作用
(7) フコキサンチン……………………坑皮膚ガン作用

以上は経口的な食餌療法を的にした成績であるが(7)についてはタラソテラピー上意義があり，経皮経粘膜効果関連の皮膚ガンの坑発ガンプロモーション活性が認められている。1998年岩手県大槌町漁協(倉沢重司組合長)は世界ではじめて“めかぶ石鹸”を製造し，岩手県の“産業まつり”で銅賞を受賞した。この石鹸は老幼弱者の皮膚によい無添加の自然にやさしい石鹸として評価される。また，(2)，(3)，(4)，(6)，(7)の研究に関連し興味深い。

La mer 38 : 50, 2000
Société franco-japonaise d'océanographie, Tokyo

資　料

日仏海洋学会うみ（La mer）第38巻第1号掲載欧文論文要旨

Wagdyy Labin*：変動の激しい海域における植物プランクトンの短期間変動とその周辺の条件

アレキサンドリア西方の，変動の激しいMex Bayに設定した定点の表層における，植物プランクトンの現存量の変動と遷移を調査した。本測点における調査は1992年5月26日から9月4日までの50日間行った。本湾は陸域に起源する大量の栄養塩負荷を受けている。クロロフィル*a*や溶存酸素の異常なまでの増加などで示されるような，藻類の著しい発達と共に，著しい物理化学的変動が観察された。異なるブルームを引き起こす植物プランクトンはそれぞれ異なる栄養塩段階で最大出現度を示した。植物プランクトンのブルームは必ずしも栄養塩の増加に依存しなかった。植物プランクトンはそれぞれ異なる推移を示し，主な植物プランクトンの優占種の著しい遷移が見られた。群集組成は数日の間に変化し，他の種が入れ替わって濃密なブルームを形成した。（*National Institute of Oceanography and Fisheries, Kayet Bay, Anfoshi, Alexandoria, Egypt）

鷲見浩一*・和田明：人工リーフによる二枚貝生息場の好適化に関する研究**

人工リーフの波浪減衰機能を利用して二枚貝の生息環境を好適化する技術開発が望まれており，貝の良好な生息場の創出には，波浪・海浜流の適度な制御を行う必要がある。そこで本研究は，人工リーフによる波浪場と海浜流場への制御効果を水理実験と数値計算により検討した。

水理実験では，海岸に複数の人工リーフを設置する際に堤間距離（開口幅）と堤長の変化が，流況パターンにどのように影響するか考察を加え，堤長と開口幅の比を用いて流況パターン区分を行った。この流況区分を用い海浜流に定常的な循環流を形成させ，その内部の水塊に幼生を捕捉させることで，幼生の逸散抑止が期待できる。

数値実験では，貝の生息場安定化をねらって5基の人工リーフが構築された北海道の浜中湾について，波浪と海浜流の場をシミュレートした。波高は堤体背後域で人工リーフ無の場合と比較して3割程度低減していた。流速は人工リーフ無の流速よりも弱められており，幼生の滞留時間が長期化し，着底を促進できると考えられる。各計算点での流速は貝の移動限界流速を下回り，人工リーフは貝の打ち上げを抑止できると思われ，人工リーフの生息場安定化への有用性が示された。（*名古屋大学工学部土木工学科　〒464-8603　名古屋市千種区不老町，**日本大学生産工学部土木学科　〒275-8575　習志野市泉町1-2-1）

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学会記事

1. 2000年3月8日（水） 東京水産大学において会長選挙の開票が行われ，平成12・13年度会長として須藤英雄会員が選出された。

2. 2000年3月11日（土） 日仏会館において，本学会共催の日仏会館シンポジウム「科学の進歩と人間の未来」が開催され，多数の来聴者があった。

3. 2000年4月24日（月） 東京水産大学において，平成12年度第1回幹事会が開かれた。主な議事は下記の通り。

1)平成12・13年度評議員選挙開票結果について
2)平成12・13年度会長選挙開票結果について
3)平成12・13年度副会長，幹事，監事の選出について
4)平成11年度事業報告
5)平成12度学会賞受賞候補者選考経過および結果報告
6)平成11年度収支決算および監査報告
7)平成12年度事業計画（案）審議
8)平成12年度予算（案）審議
9)平成12年度学会賞候補者推薦委員会委員の選出
10)その他

4. 2000年5月25日（木） 東京水産大学において平成12年度第2回幹事会および評議員会が開かれた。主な議事は下記の通り。

1)平成12・13年度評議員選挙開票結果について
　会長より学会会則第9条にもとづいて佐伯和昭，吉田次郎，田中祐志各会員を評議員として追加委嘱したい旨提案され了承した。
2)平成12・13年度会長選挙開票結果について
3)平成12・13年度副会長，幹事，監事の選出について
4)平成11年度事業報告
5)平成12度学会賞受賞候補者選考経過および結果報告
6)平成11年度収支決算および監査報告
7)平成12年度事業計画（案）審議
8)平成12年度予算（案）審議
9)平成12年度学会賞候補者推薦委員会委員の選出
10)その他
　ア．平成12年度科学研究費補助金の申請を行ったが不採択との通知があった。
　イ．評議員の投票にもとづいて第18期学術会議会員候補者および推薦人を選出し，学術会議へ届け出た。
　ウ．評議員の投票にもとづいて，学術会議水産学研究連絡委員会へ科学研究費補助金審査員候補者の推薦を行った。
　エ．学会の活性化について引き続き検討していくこととなった。
　オ．本学会の名誉会員として高木和徳会員を推挙することが諮られ，了承した。
　カ．学会誌の残部状況が報告され，バックナンバーの処理について検討することとした。
　キ．学会の創立40周年記念事業として記念誌の発行が提案され，審議の結果今年度の学会誌の発行に支障を来さないのであれば，第38巻のいずれかの号をこれに当て，内容は第19巻以降の総目次を優先することとした。

5. 本学会から「2000年度日仏学者交換事業」に推薦した Fabrice Lizon 氏の来日が決定した。滞在中の日程と活動予定は下記の通り。

1)滞在期間：2000年6月18日～6月26日
2)講演（日仏会館） 6月23日（金）18:00～20:00
　一般向け講演（通訳付き），入場無料
　「Phytoplankton life in tidally mixed coastal water（潮流によって混合した沿岸域における植物プランクトンの生態について）」
3)特別講演（日仏海洋学会学術研究発表会） 6月18日（日）16:00～17:00
　「Photoadaptation and primary production of phytoplankton in tidally mixed coastal water」
4)学術講演（東京水産大学252教室） 6月22日（木）15:00～
　「Kinetics and Lagrangian model of photoadaptation processes in tidally mixed coastal water」

6. 2000年6月18日（日） 日仏会館会議室において平成12年度学術研究発表会が開かれた。発表題目と発表者は次の通り。

午前（9:00～12:00）

1. 低塩分及び高塩分環境に生息する細菌と古細菌から構成される天然微生物群集が示すGS I（グラム染色指標） ………………○才田春夫[1]・亀倉正博[2]・Wael S.M. El-Sayed[3]・Mohamed Abu-Shady[3]・安部征雄[1]・山口智治[1]・Yang Peiling[4]・

前川孝昭[1]・関　文威[1]（[1]筑波大，[2]野田産科研，[3]Ain Shams Univ., [4]China Agri. Univ.）

2. 霞ヶ浦における植物プランクトンにおよぼす生簀養鯉の影響 ……○東　陽介・中根　剛（筑波大）・熊丸敦郎（茨城・内水試）
3. 植物プランクトン群集の蛍光分光法による種類構成の評価……………………○松沢勇志・桑原朋彦・関　文威（筑波大）
4. 断続光の明暗周期変化と植物プランクトンの増殖量との関係……○渡部　武・山崎七重・荒川久幸・森永　勤（東水大）
5. 水柱内での溶存メタン酸化—東京湾，霞ヶ浦，野尻湖を例にして—
…○内海真生（筑波大）・野尻幸宏（国立環境研）・中村岳史（東水大）
6. 太平洋流動解析に基づく液化CO_2海洋隔離の可能性の検討
……和田　明・○長谷川一幸（日大・生産工）・高野憲治（コロンビア大）
7. 乱流観測装置の開発について
………………………………○山崎秀勝（東水大）
8. Microscale processes in the ocean; why are they so important for ecosystem functioning?
……○Seuront, Laurent(Tokyo Univ. of Fish.)
9. Numerical simulation of density current in Tokyo Bay
…○Ivonne, R., Y. Kitade and M. Matsuyama (Tokyo Univ. of Fish.)
10. Behavir of low saline water along the coast of Miura Peninsula near the mouth of Tokyo Bay
………○Iwayan, N., M. Matsuyama, Y. Kitade and J. Yoshida(Tokyo Univ. of Fish.)
11. 衛生赤外画像パーソナルコンピュータ受信からみた黒潮フロントの力学的特性……………○中村重久
12. アラビア海，インド洋，メキシコ湾から採取されたドリルコアサンプルの鉱物・化学組成
………………………………○青木三郎（東洋大）

午後（13:00～13:45）

13. 新しい海洋療法—深海療法（Abyssotherapie）とめかぶ療法（Sporophylltherapie）について
…………………○野村　正（日海療研・東北大）

〔特別講演〕（16:00～17:00）

「Photoadaptation and primary production of phytoplankton in a tidally mixed coastal water」
Fabrice Lizon (Univrsite des Sciences et Technologies de Lille)

7. 2000年6月18日（日）　日仏会館会議室において第41回（平成12年度）総会が開かれた。議事の概要は次の通り。

1)平成12・13年度評議員選挙開票結果について（裏表紙参照）

2)平成12・13年度会長選挙開票結果について（裏表紙参照）

3)平成12・13年度副会長，幹事，監事の選出について（裏表紙参照）

4)平成11年度事業報告

(a)庶務

	平成11年4月	入会	退会	逝去	資格変更	平成12年4月
名誉会員	1	–	–	–	–	1
正会員	286	4	12	2	–	276
学生会員	2	1	–	–	–	3
賛助会員	16	–	2	–	–	14

活動状況

評議員会	1回
幹事会	2回
総　会	1回
学術研究発表会	1回
学会誌発行	
学会賞授与	須藤英雄（立正大学）
シンポジウムの開催	1回（共催）

(b)編集

学会誌「La mer」4号刊行

5)平成12度学会賞受賞候補者選考経過報告（詳細は参照）

6)平成11年度収支決算および監査報告

収　入

前年度繰越金	61,765	
正会員会費	1,050,000	(延べ175名)
学生会員会費	8,000	(　2名)
賛助会員会費	210,000	(15社　21口)
学会誌売上金	357,693	(大学，出版社等購読料)
広　告　料	70,000	(4社)
別刷印刷費	345,000	
著者負担印刷費	440,000	
雑　収　入	63,545	(学術著作権使用料等)
寄付金収入	43,700	
合　計	2,650,103	

支出		
学会誌印刷費	1,307,350	
送料・通信費	301,435	
事務費	704,128	（人件費・封筒事務用品等）
交通費	25,230	
会議費	32,580	（会場使用料等含む）
学会賞経費	73,185	（賞金・賞状・メダル等）
雑費	31,036	（郵便・銀行外為手数料他）
予備費	0	
小計	2,474,944	
次年度繰越金	175,159	
合計	2,650,103	

7)平成12年度事業計画（案）審議

下記原案通り承認された。

評議員会，総会，学術研究発表会，幹事会の開催

学会誌「La mer」の刊行

平成12度学会賞授与及び平成13年度受賞候補者の推薦

その他

8)平成12年度予算（案）審議

原案通り承認された。

収入	
前年度繰越金	175,159
正会員会費	1,656,000
学生会員会費	12,000
賛助会員会費	200,000
学会誌売上金	360,000
広告料	100,000
別刷印刷費	400,000
著者負担印刷費	400,000
雑収入	50,000
寄付金収入	1
合計	3,353,160

支出	
学会誌印刷費	2,200,000
送料・通信費	250,000
事務費	700,000
交通費	25,000
会議費	25,000
学会賞経費	75,000
雑費	50,000
予備費	28,160
合計	3,353,160

9)平成12年度学会賞候補者推薦委員会委員の選出結果報告

青木三郎　今脇資郎　落合正宏　岸野元彰
小池　隆　関　文威　関根義彦　竹松　伸
松生　洽　前川行幸　松山優治　門谷　茂
柳　哲雄　山口征矢

10)その他

a)高木和徳会員を名誉会員に推挙することが承認された。

b)学会誌のバックナンバーの残部数の状況が報告され，その売却について原案が了承された。

引き続いて関　文威会員への学会賞授与と受賞記念講演が行われた。また終了後懇親会が別席で開かれ，盛会裡に終了した。

8. 平成12年度日仏海洋学会賞

受賞者：関　文威（筑波大学生物科学系）

受賞課題：海洋食物網における腐食連鎖の卓越性に関する主導的研究

推薦理由：生物圏を構成しているすべての生態系では，被食者と捕食者と関係における繋がりは，生態系の機能から生きている生物を直接に食う連鎖である生食連鎖と，死骸または生体の破片や排出物を食う連鎖である腐食連鎖によって構成されている。この両者の関係において，一般科学や教養生物学においては，現在なお，次のように理解されてきている。すなわち，陸域においては，樹冠ないし草木層では生食連鎖し，地上あるいは土壌中では腐食連鎖が卓越して，全体としては後者が卓越する。これに対して，海洋においては，生産層では生食連鎖が卓越し，分解層では腐食連鎖が卓越して，全体としては前者が卓越する。

この一般概念の科学的な誤りを，1960年代初期に海洋生化学の立場から初めて暗示したのが J. D. H. Strickland 博士であり，1960年代中期に海洋微生物学の立場から実験生態学的研究と海洋観測結果との結果を解析して初めて実質的に証明したのが関　文威会員である。関会員による本課題における先駆的な貢献は，1972年にUNESCOが主催した IBP-UNESCO Symposium「Detritus and its Role in Aquatic Ecosystems」における招待講演 “The role of microorganisms in the marine food chain with reference to organic aggregate (Seki, 1972)” が，このシンポジウムの最も重要な講演であったとの講評がConclusive Remarks of the IBP-UNESCO Symposium の最後の部分に記載されていることで明白である。

関会員が先駆的に科学実証したこと，すなわち「海洋においては，生産層でも分解層でも腐食連鎖が卓越して，その結果として海洋全体としても腐食連鎖が卓

越すること」は，その後も世界的に多くの海洋生態学者が種々な角度から研究を重ねて大同小異の結果を得ている。それらの研究結果の共通した結論から，海洋食物網における腐食連鎖の卓越性は，現在では海洋生態学上の常識となっている。このようにして確立された専門分野における常識は，早晩，一般科学や教養生物学においても常識になることに疑いはない。

関会員が，国際海洋科学界に先駆けて，1960年代に既に明らかにしたこの現象の係わる知識は，海洋科学の係わる単なる科学的興味を超えて，人類と地球環境の調和が叫ばれている今日の人間社会が，海洋に対する人為的攪乱を解消するための望ましい方向付けをする際にも，大いに役立つものである。本委員会は，同博士の研究が海洋微生物学の進展に寄与するところが顕著であり，本学会賞の授与にふさわしいものとしてここに推薦する。

学会賞受賞候補者推薦委員会
委員長　松山　優治

主要論文

1. Seki, H. (1964): Studies on microbial participation to food cycle in the sea 1. Participation in the microcosm at static condition. J. Oceanogr. Soc. Japan **20**:122–134.
2. Seki, H. (1965): Studies on microbial participation to food cycle in the sea 2. Carbohydrate as the only organic source in the microcosm. J. Oceanogr. Soc. Japan **21**: 278–285.
3. Seki, H. (1966): Seasonal fluctuation of heterotrophic bacteria in the sea of Aburatsubo Inlet. J. Oceanogr. Soc. Japan **22**: 92–104.
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5. Seki, H. (1967): Microbial assimilation of carbon dioxide in the Japan Trench. J. Oceanogr. Soc. Japan **23**: 182–188. (with C. E. Zobell)
6. Seki, H. (1968): Observations on the decomposition of a marine sediment. Limnol. Oceanogr. **13**: 440–447. (with Skelding, J. and Parsons. T.R.)
7. Seki, H. (1969): Marine bacteria and other heterotrophs as food for zooplankton in the Strait of Georgia during winter. J.Fish.Res.Bd. Canada 26: 3165–3173. (with Kennedy, O. D.)
8. Seki, H. (1969): Marine microorganisms associated with the food of young salmon. Appl. Microbiol. **17**: 252–255.
9. Seki, H. (1970): Microbial biomass on particulate organic matter in seawater of the euphotic zone. Appl. Microbiol. **19**: 960–962.
10. Seki, H. (1970): Microbial biomass in the eutrophic zone of the North Pacific Subarctic Water. Pacific Science **24**: 269–274.
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16. Seki, H. (1974): Decomposition of particulate organic materials in Tokyo Bay at summer stagnation period in 1972. La mer **12**: 9 – 15. (with Shinoyama, H., Muto, M. and Numanoi, H.)
17. Seki, H. (1978): Experimental decay of eelgrass (Zostera marina) into detritus particles. Arch. Hydrobiol. **84**: 109–119. (with Yokohama, Y.)
18. Seki, H. (1981): Microbial readjustment to new balance after influx change of inorganic material in marine dysphotic layer. Water Air Pollut. **16**: 331–337. (Aoshima, N. Whitney, F.A. and Wong, C.S.)
19. Seki, H. (1981): Uptake kinetics of dissolved organic materials in a marine ecosystem with experimental precedence of the detritus food chain. Arch. Hydrobiol. **92**: 409 – 418. (with, Whitney, F. and Wong, C.S.)
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Ecosystems. CRC Press, Boca RAton. 201pp.

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9. 新入会員（正会員・学生会員）

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Fabrice Lizon	Station Marine de Wimereux CNRS UPRES-A 8013 ELICO Universite des Scientes et Technologies de Lille BP 80, 62930 Wimereux, France	山崎秀勝

10. 所属・住所等変更

（正会員・受付順）

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野村英明	東京大学海洋研究所 〒164-8639　中野区南台1-15-1

（賛助会員・社名変更）

新日本気象	〒154-0012　世田谷区駒沢3-15-1

11. 退会（正会員・賛助会員）

山田佳昭，小網汪世，読売広告社，
自然情報環境研究所

12. 受贈図書（受付順）

NTT R&D　49 (2～8)
広島日仏協会報　147～149
農業工業研究所ニュース　16, 17
なつしま　169, 171～175
東海大学紀要（海洋学部）　49, 50
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勇魚　22
Bulletin of the National Science Museum　26(1)
養殖研究所研究報告　29
農業工業研究所報告　39
神奈川県立博物館研究報告　29
Preliminary Report of the Hakuho Maru Cruise KH-98-2
サイエンスボランティア事業
日本海区底魚資源研究連絡会議報告（平成9・10年度）
水産工業研究所　しおさい　15, 16
水産工業研究所研究報告　21
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東海大学海洋研究所研究報告　21
東海大学海洋研究所年報　21
日仏理工学会誌　8
Ship & Ocean News Letter
農業工業関係研究所成果情報　平成11年度
OKEAHOПO ГИЯ　39(4-6), 40(1, 2)
Journal of the Korean Society of Oceanography 35 (1, 2)
Meereswissenshaftliche Berichte　38～40
海洋水産研究　20(2)
海洋与湖沼　30(6), 31(1)
青島海洋大学学報　29(3, 4)
Ocean Research　22(1)

賛助会員

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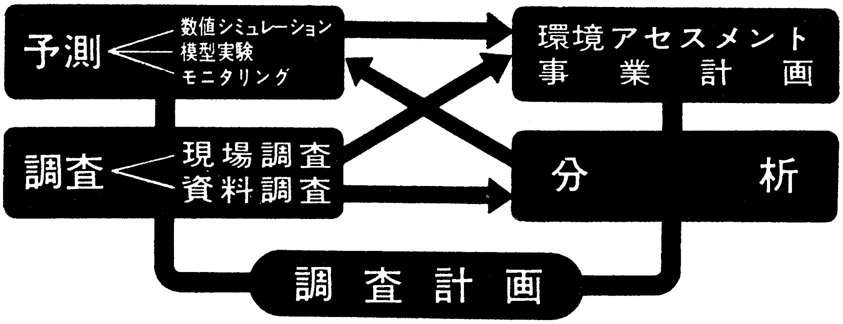
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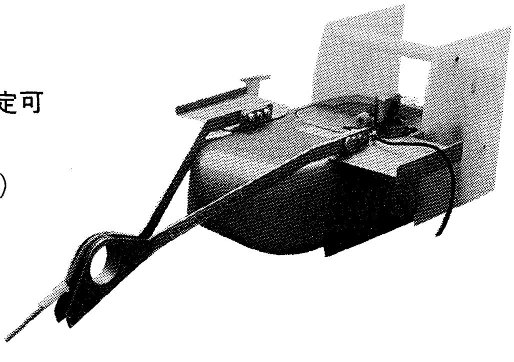

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