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RELATIONSHIP BETWEEN SEDIMENT POLLUTION AND MACROBENTHIC COMMUNITIES IN HIROSHIMA BAY, JAPAN

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ABSTRACT

Distribution of sediment, macrobenthos, and the anoxic water mass in Hiroshima Bay was investigated. The accumulation of organic matter in the sediment was considerable in the semi-closed bays, such as Kure and Edajima, and in the mouth of the Ota River. In Kure Bay, particularly, the benthic communities were of very poor condition or had disappeared, apparently due to the anoxic water mass. It is thought that the occurrence of the anoxic water mass in Kure Bay was mainly caused by the oxygen demand due to decomposition of the organic matter in the sediment, which can be determined from the distribution of the temperature, salinity, and dissolved oxygen and from the subtidal current.

INTRODUCTION

Background

Bottom-water anoxia is considerable in semi-enclosed bays, such as the Inland Sea and Mikawa and Tokyo Bays on the coast of Japan. The Inland Sea alone contains more than 10 small bays and seas, and for some of them, the occurrence of an anoxic water mass and its effects on the macrobenthos have been reported (Shimada 1983). Anoxic water masses have occurred in Hiuchi-Nada and Harima-Nada Seas during summers. In the summer of 1972, these seas experienced a great decline in fish and shellfish due to a large-scale anoxic water mass (Imabayashi 1983). Also, in Osaka Bay, it was reported that the benthic community was greatly affected by the anoxic water mass (Jo, Yamochi, and Abe 1978a, b).

A decline in fish and shellfish due to the occurrence of a large-scale anoxic water mass was also reported in Mikawa Bay (Aichi Prefecture Fisheries Experimental Station 1973, 1974), and a similar decline has become serious in Tokyo Bay. The occurrences and upwellings of anoxic water are called "blue tide" because they appear blue (or white) as a result of the surface flow with wind blowing.

In every area where an anoxic water mass has been noted, pollution from organic matter was evident; thus, it can be assumed that the oxygen demand of the organic matter caused the anoxic water mass occurrences. Therefore, in discussing the effects of sediment pollution on macrobenthos, we must consider the anoxic water mass occurrences as well as heavy metals and artificial organic matter. This paper summarizes a study of an anoxic water mass and its effects on the macrobenthic communities of Hiroshima Bay (particularly Kure Bay).

Description of Hiroshima Bay

Hiroshima Bay is located in western Japan, in the western portion of the Inland Sea. The surface area is 946-km^2 wide, with a volume of 24.2 km^3 (Figure 1). The bay is dotted with many small islands. The sea to the north of Itsukushima, Nomijima, Edajima, and Kurahashijima Islands is divided into two semi-enclosed bays, Edajima and Kure. The sea bottom is generally plain, with a limited portion of shoal along the seacoast and a sea valley along the channel.

The main rivers draining into the bay are Ota, Seno, and Yahata in the northern end of the bay and Nishiki, Kose, and Megumi in the western part of the midbay. The flux volumes in summer are approximately 6 million m^3 per day for Ota River, 4 million m^3 per day for Nishiki River, 1 million m^3 per day for Kose River, and under 0.3 million m^3 per day for the other rivers.

The flood tide enters the bay south of Kurahshijima Island, heads north, and enters Kure Bay, turning to the northeast. The ebb tide flows out, heading toward the opposite direction. Tide speeds are approximately 10 cm/sec in the northern end of the bay, approximately 20 cm/sec in the midbay, and 30 to 40 cm/sec at the mouth and channel of the bay (Figure 2) (Third District Port Construction Bureau of the Transportation Ministry 1980).

STUDY DESCRIPTION

Observations in 1982

Observations of water quality (June-October), sediment (August), and benthic communities were performed in 1982 at the stations shown in Figure 3.

Water temperature and salinity were measured by electric water thermometer and salinometer. Water was sampled from the surface and the bottom with an insulated water sampler. The sediment was sampled by divers with an acrylic core sampler. The upper 5-cm portion was separated. The samples were analyzed for organic content (by ignition loss, 900° C, 2 hr), chemical oxygen demand (consumption of potassium permanganate), and sulfide (distillation by steam-iodometry).

Benthic communities were sampled with a Smith-McIntyre sampler and sieved with a 1-mm sieve. Organisms were fixed in formalin.

Observations in 1983

From July through October, dissolved oxygen (DO) in the bottom water was observed at 1-week intervals at observation stations in the northern end of the bay (see Figure 4). Procedures for sampling were the same as in 1982.

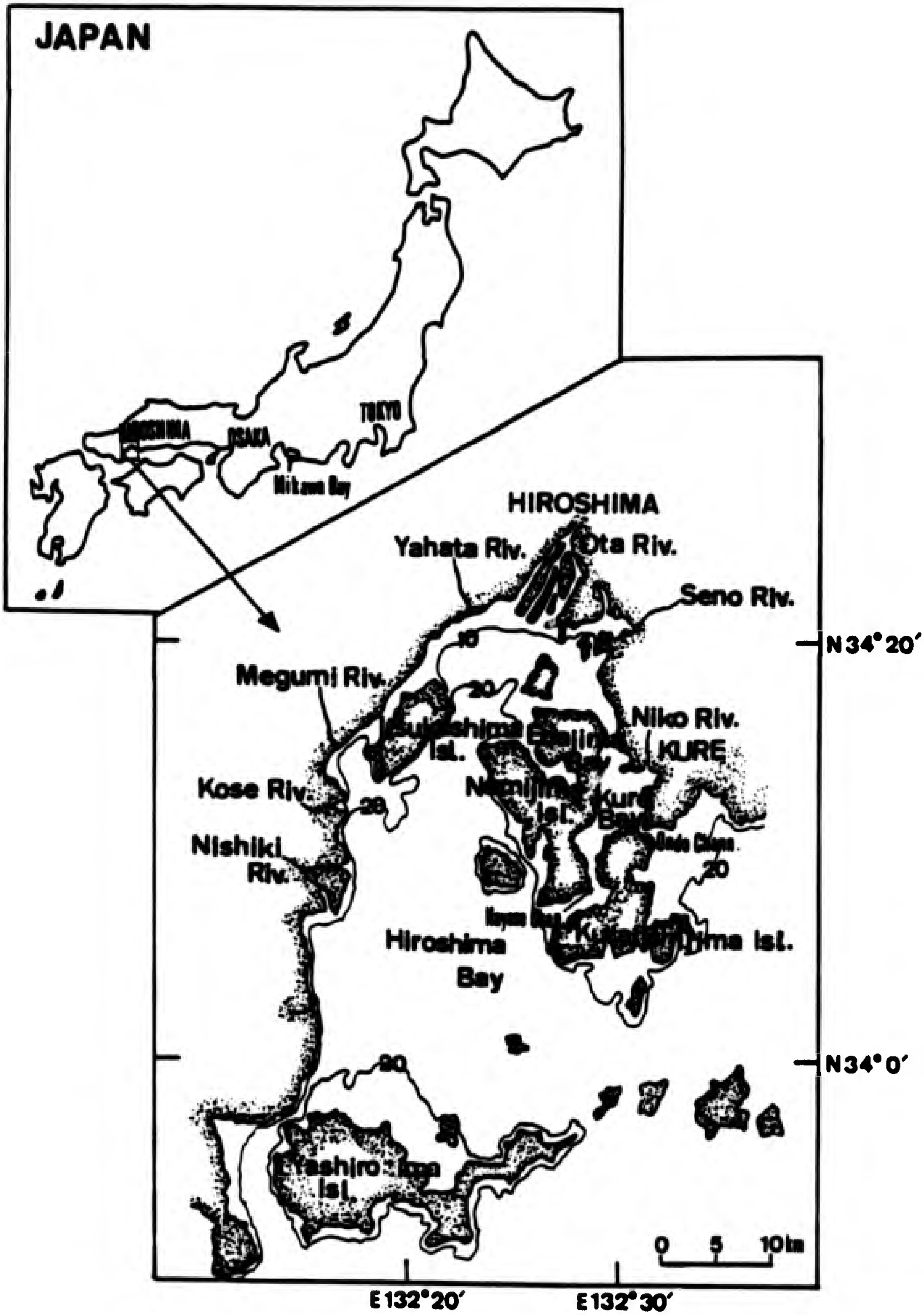
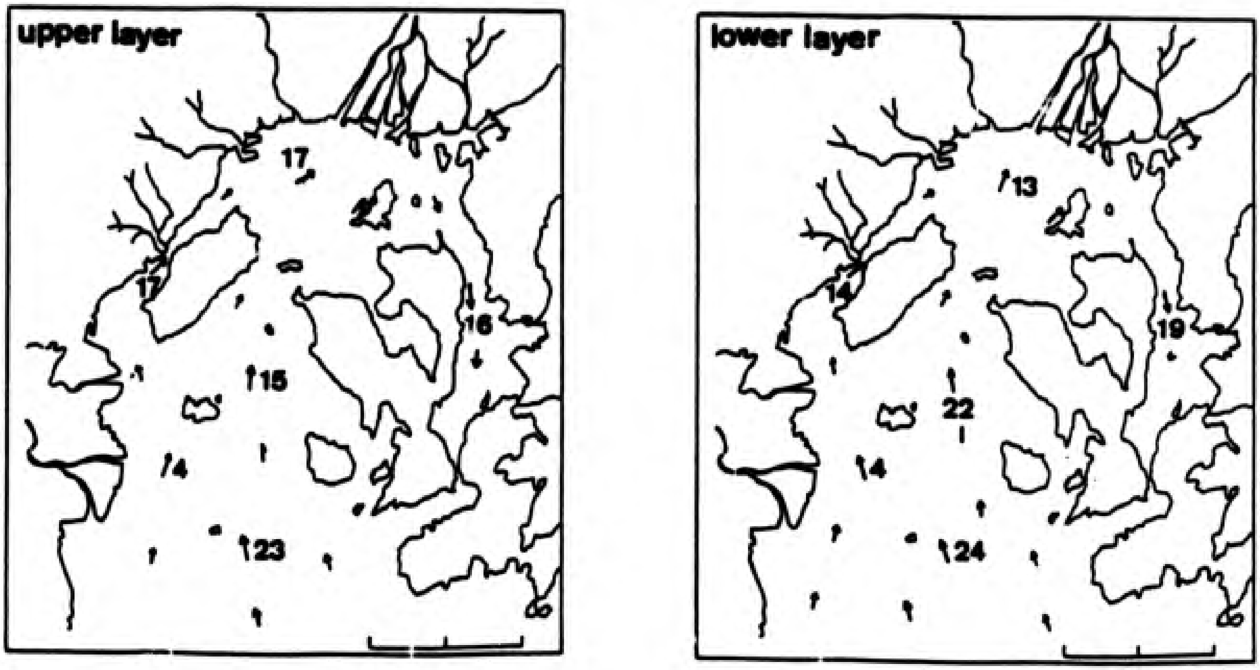
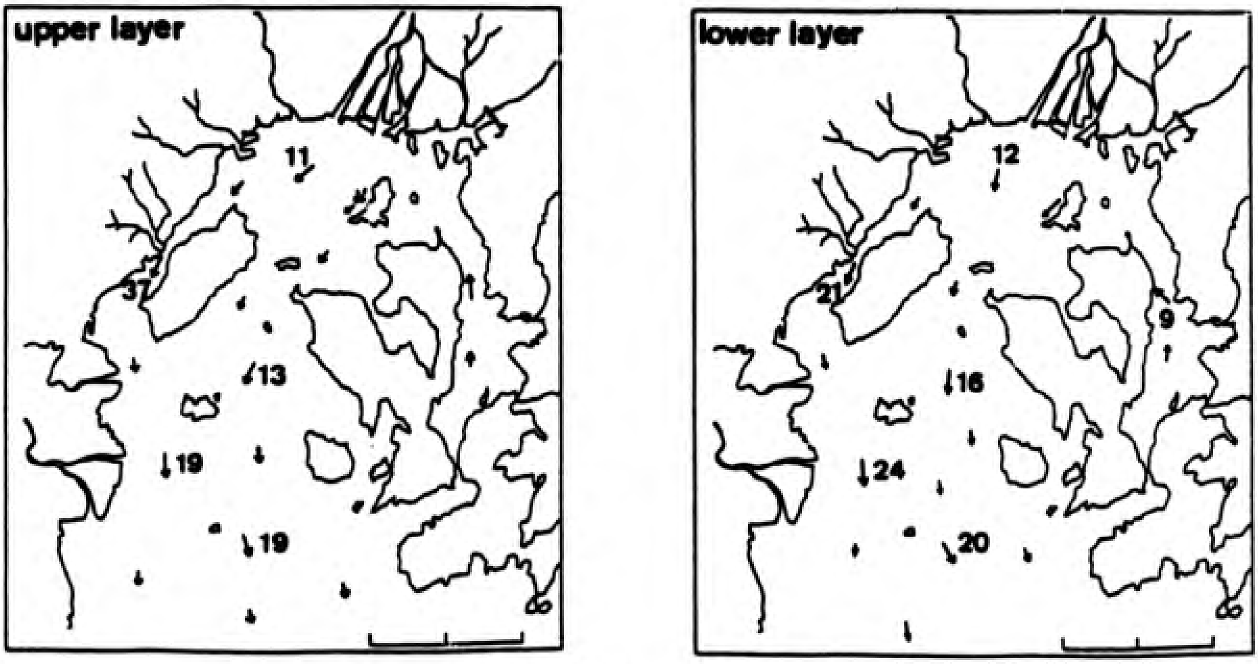


Figure 1. Study area, Hiroshima Bay



a. Flood tide



b. Ebb tide

Figure 2. Average tidal currents (centimetres per second) in Hiroshima Bay during the spring

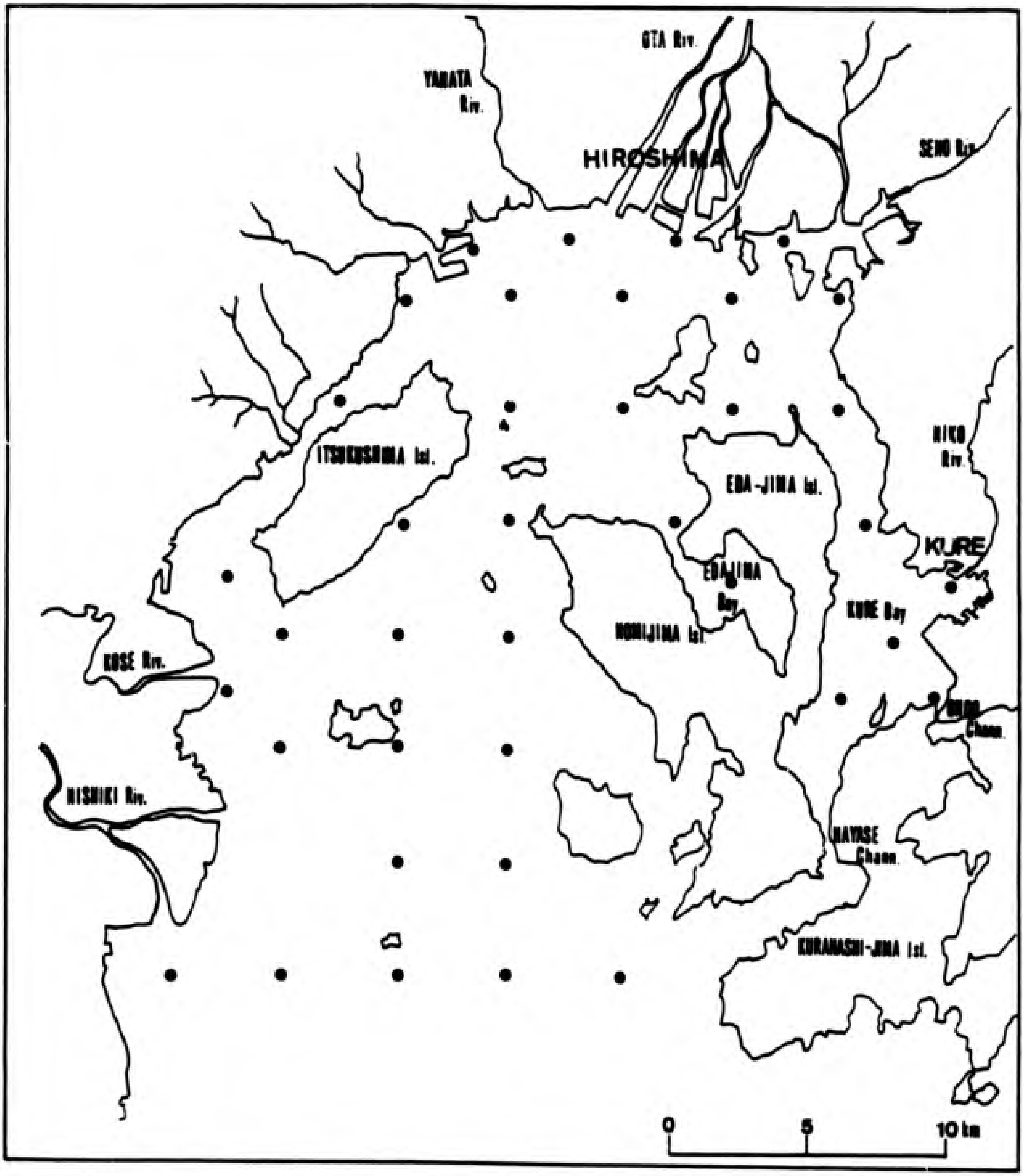


Figure 3. Observation stations in 1982

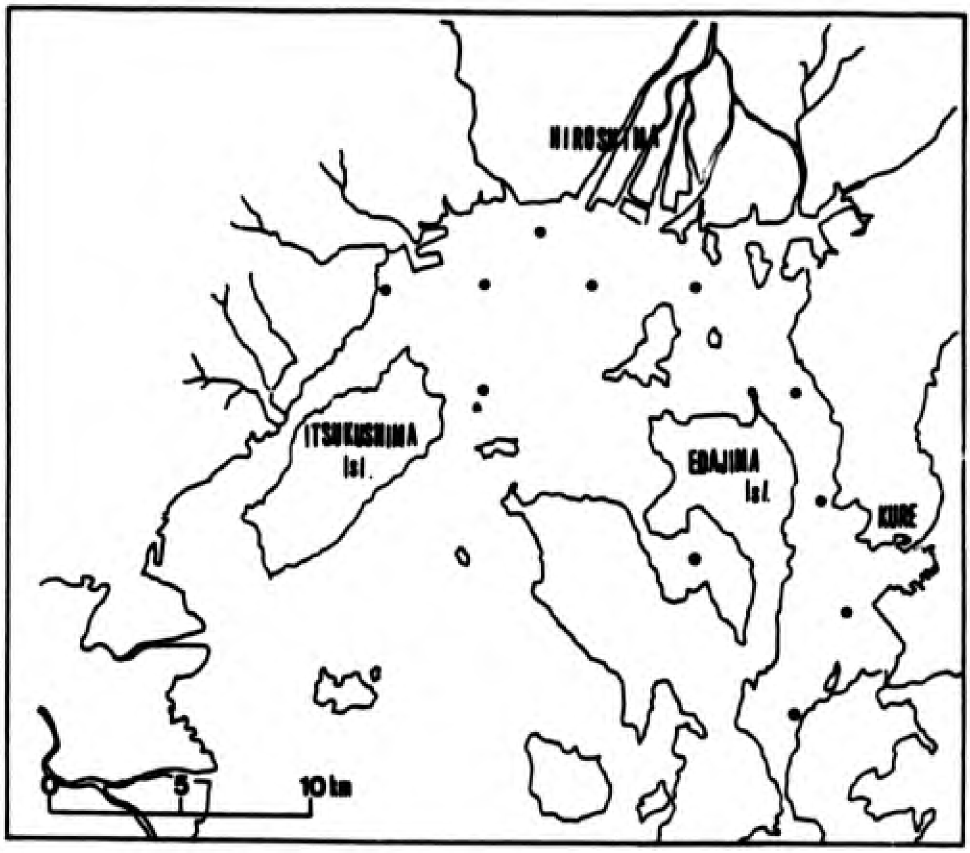


Figure 4. Observation stations in 1983

Experiments in 1984

At those observation stations shown in Figure 5, the sediment was sampled by divers with an acrylic core sampler and incubated with water from directly above it. The oxygen consumption rate was measured by analyzing diminished oxygen in the water under a constant temperature of 25° C for 5 days.

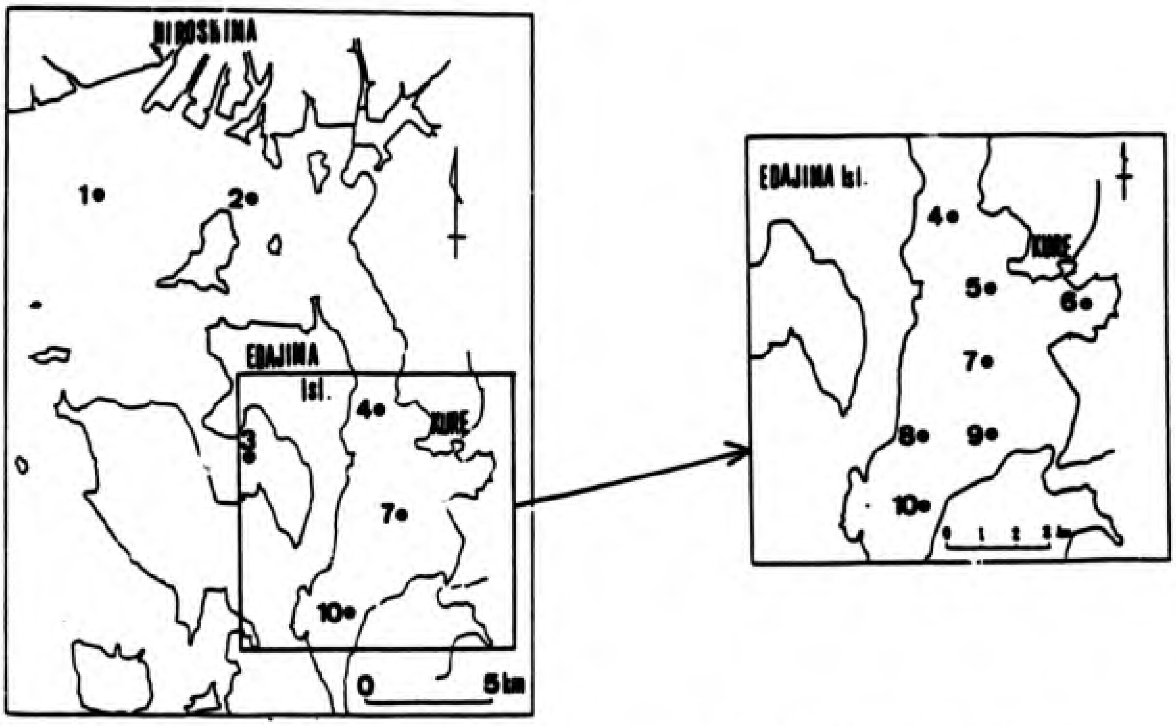
Observations in 1984-87

At the six observation stations shown in Figure 5a, observations were made of the water quality, the sediment, and the distribution of the macrobenthos. At the seven observations stations in Kure Bay (shown in Figure 5b), water quality was tested three times a month. The procedures were the same as in the preceding years.

RESULTS AND DISCUSSION

Observations in 1982

Dissolved oxygen in the bottom water during the period July 5-October 6, 1982, is shown in Figure 6. The observed patterns indicate that the anoxic water mass was frequently located in Edajima Bay and near the mouth of the Ota River in the northern end of the bay.



a. Stations for sediment core sampling (in 1984) and monthly observations (May 1985-February 1987)

b. Stations for observation of anoxic water mass, three times a month, July-October 1986

Figure 5. Observation stations during the period 1984-87

Patterns of ignition loss, chemical oxygen demand (COD), and sulfide in the sediment sampled during June-October 1982 are shown in Figure 7. It can be deduced from the high levels of COD and sulfide in Kure Bay, Edajima Bay, and near the mouth of the Ota River that the accumulation of organic matter in the sediment is significant in these areas.

DO Distribution, Summer 1983

Figure 8 shows the average DO concentrations in the sediment over the 12 samplings (conducted at 1-week intervals) during July 19-October 14, 1983. This indicated that Kure Bay is more likely to become anoxic in its innermost part.

Water Quality Changes, 1985-87

Figure 9 shows the changes in the water quality in Kure Bay during the period May 1985-February 1987 (average of values at three observation stations). The highest temperature in the upper water was recorded in August, with a lag of 1 or 2 months in the lower layer. The difference in temperature between the upper and lower layers was greatest during July and August. There was no outstanding transition in salinity except for the noticeable decrease in the upper layer during June and July due to heavy rain.

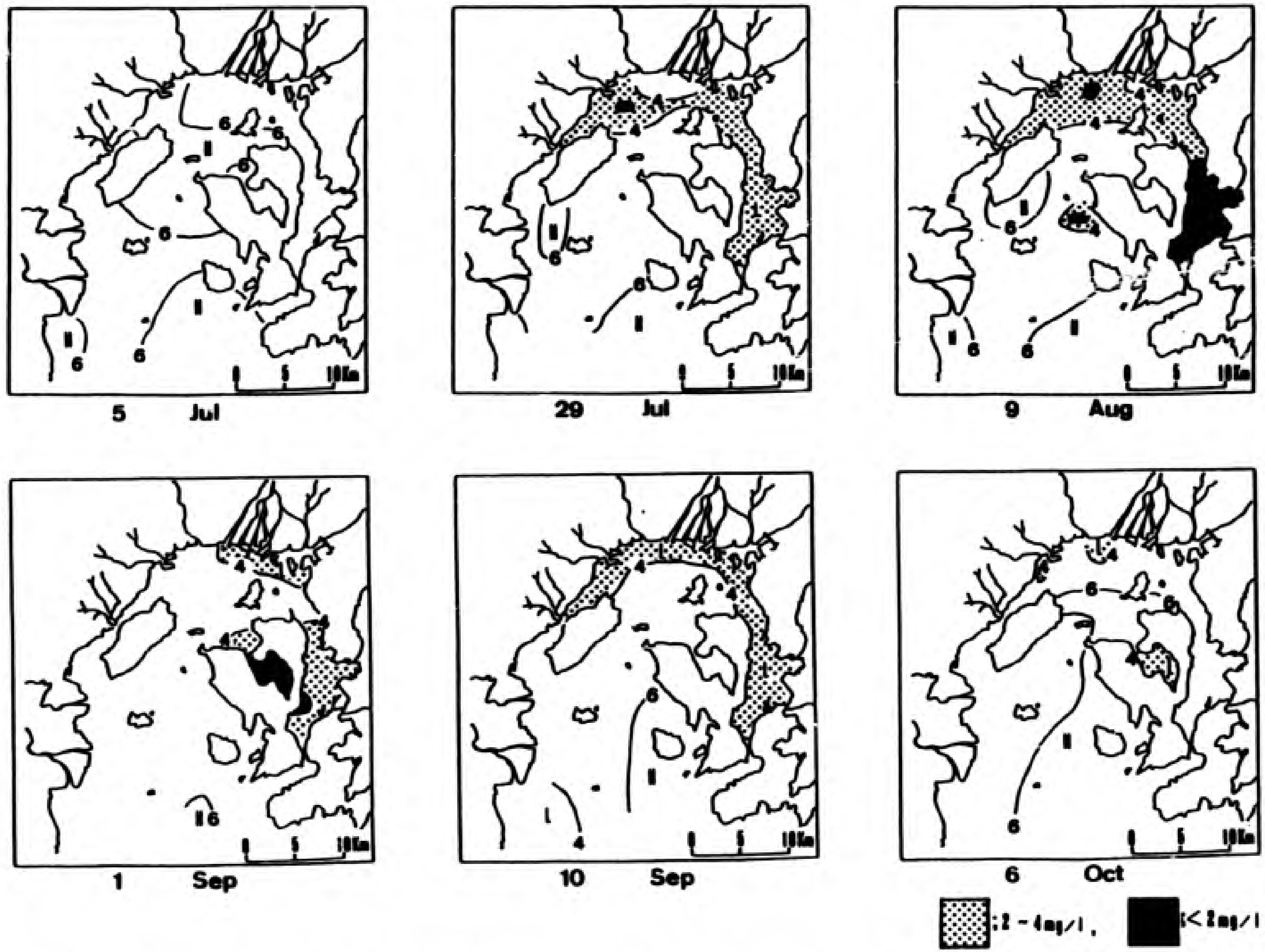
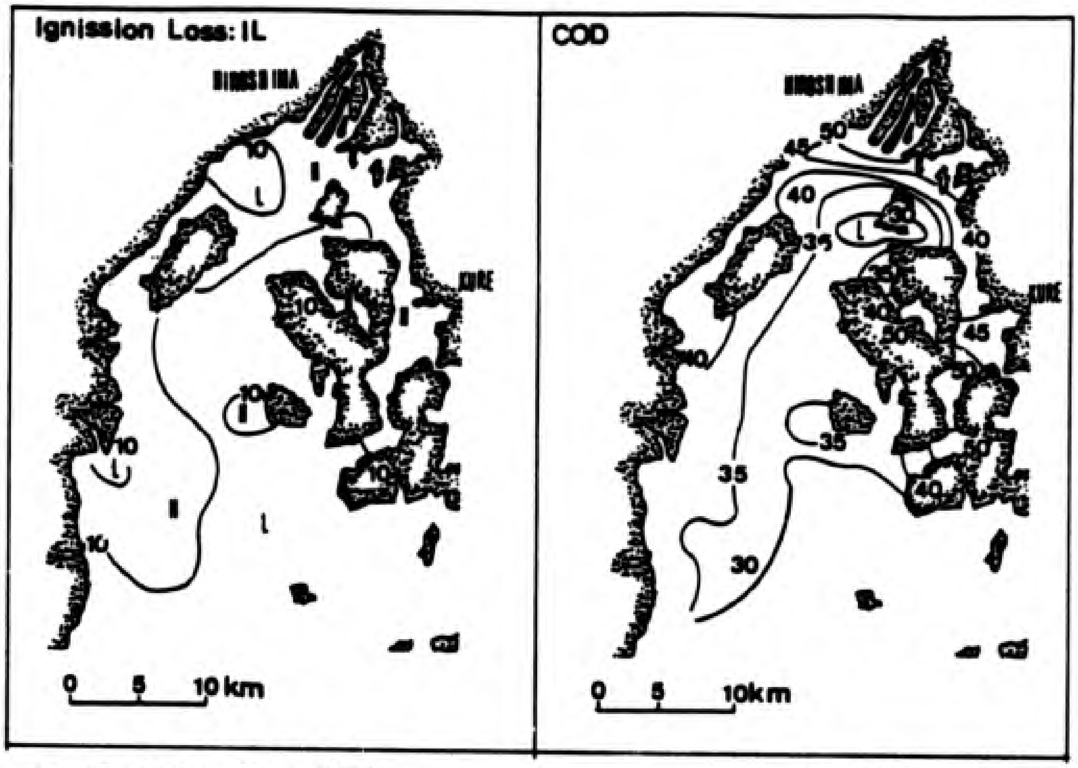
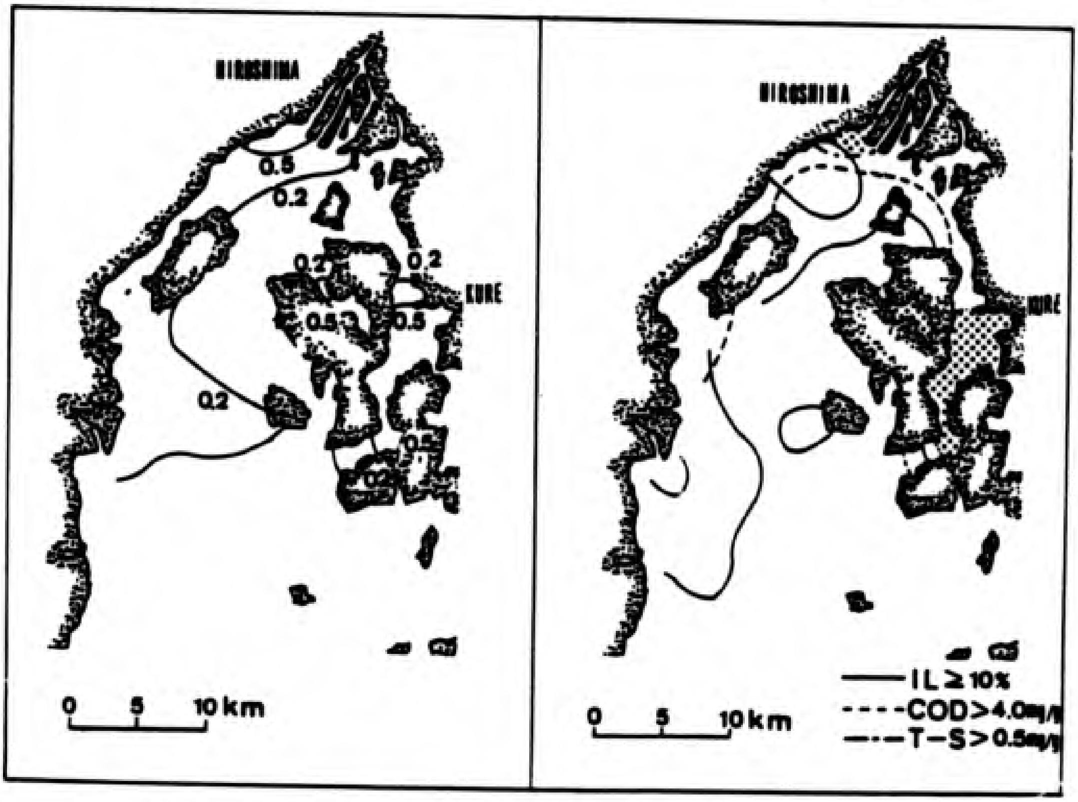


Figure 6. Pattern of DO concentration in bottom water, July 5-October 6, 1982



a. Ignition loss (IL)

b. COD



c. Total sulfide (T-S)

d. Composite

Figure 7. Patterns of selected sediment parameters in 1982

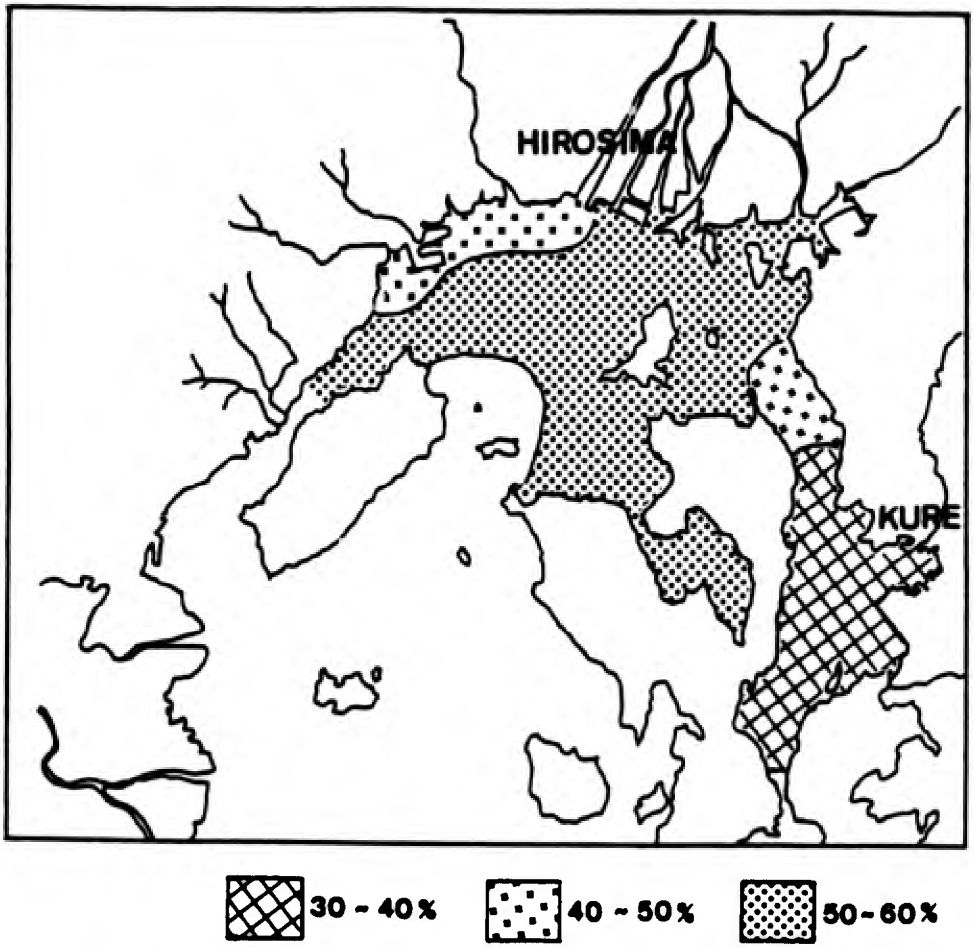


Figure 8. Deviation of DO concentrations in bottom water of Hiroshima Bay, July 19-October 14, 1983

Benthos Distribution, 1985-87

The distribution of the macrobenthos during the period June-October 1982 is shown in Figure 10. There were very few organisms in Kure and Edajima Bays.

The transition in the benthos distribution for May 1985-February 1987 is shown in Figure 11. Table 1 summarizes the data on benthos. In northern and southern Kure Bay and in the mouth of the Ota River, densities were highest. In the center of Kure Bay, however, and in Edajima Bay, lower densities were noted. Dominant organisms were Polychaeta, along with a few Mollusca and Crustacea.

Jo, Yamochi, and Abe (1978a) investigated Osaka Bay with regard to water quality and the distribution of the sediment and the benthic communities. They concluded that the areas lacking benthos existed where large accumulations of organic matter existed in the sediment, where an anoxic water mass can easily occur due to stratification.

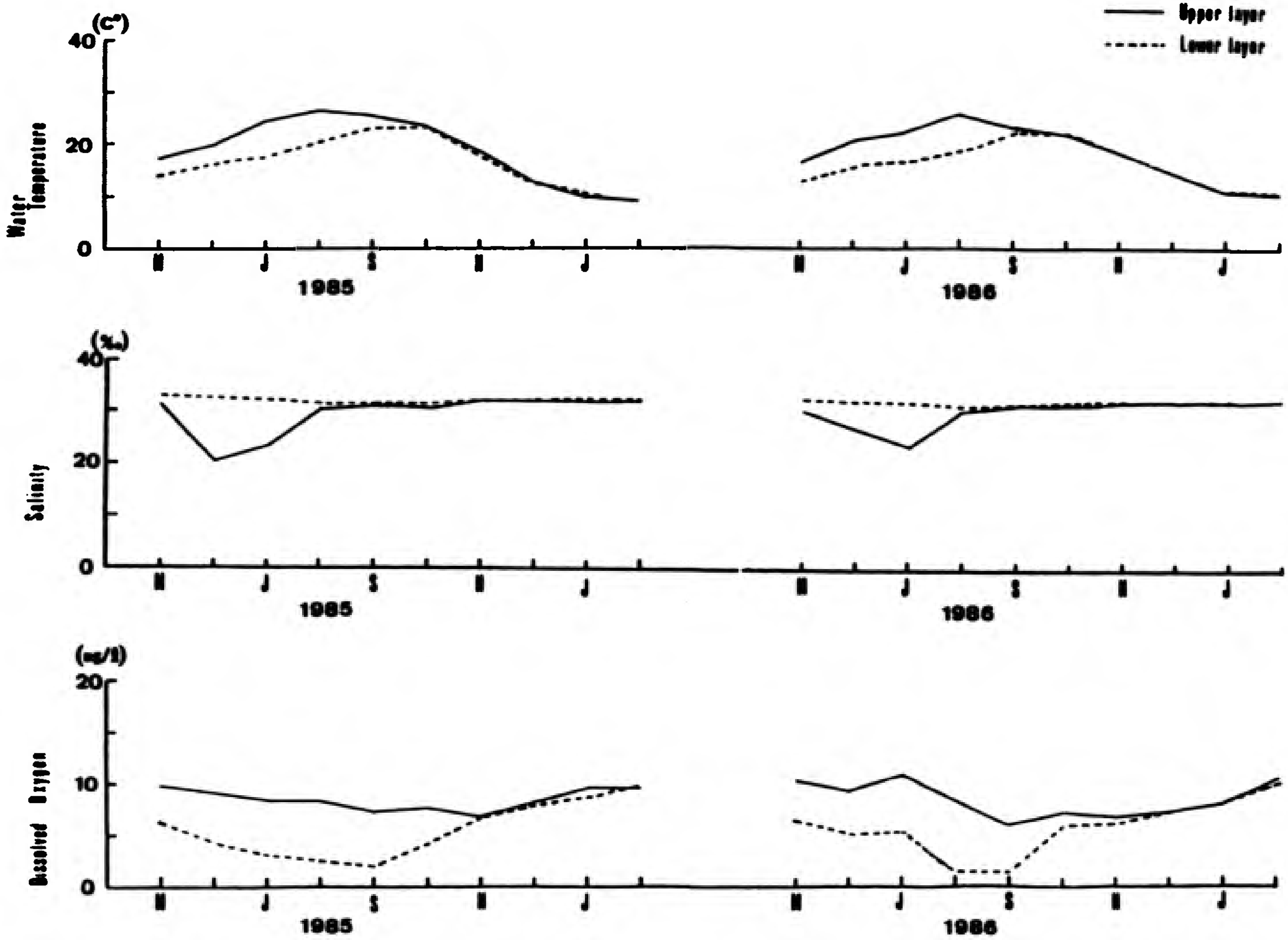


Figure 9. Fluctuations of average water quality in Kure Bay, May 1985-February 1987

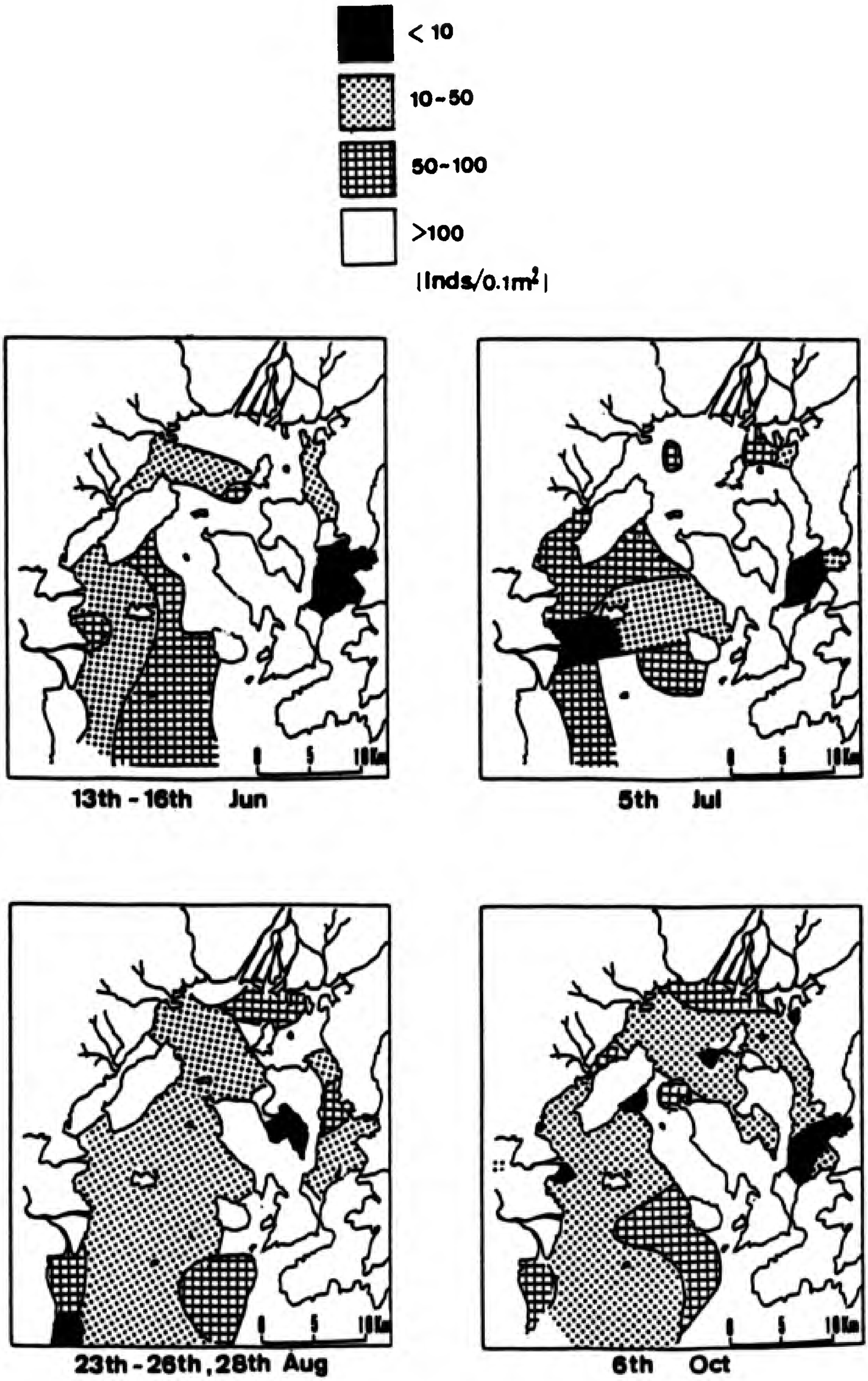


Figure 10. Distribution of macrobenthos, June-October 1982

Figure 11. Distribution of benthic community (individuals/0.1 m^2) in Kure Bay, May 1985-February 1987

TABLE 1. SUMMARY OF BENTHIC COMMUNITIES, INNER HIROSHIMA BAY, MAY 1985-FEBRUARY 1987

Parameter	St. 1*	St. 2*	St. 3**	St. 4†	St. 7†	St. 10†
Number of species††	3-21 (9)	2-19 (10)	0-14 (3)	3-15 (8)	0-3 (1)	3-18 (9)
Number of individuals††	5-99 (28)	5-68 (26)	0-50 (6)	4-111 (34)	0-12 (3)	3-107 (30)
Diversity index (H')††	0.760-2.515 (1.77)	0.500-2.604 (1.95)	0-2.200 (0.72)	0.601-2.306 (1.38)	0-1.099 (0.31)	0.950-2.203 (1.67)
Percentage composition††						
Annelida	33.3-100 (74)	45.2-100 (79)	0-100 (77)	50-100 (87)	8.3-100 (85)	40-100 (81)
Mollusca	0-57.6 (14)	0-52.4 (10)	0-50.0 (8)	0-50.0 (8)	0-91.7 (15)	0-60.0 (16)
Arthropoda	0-25.0 (6)	0-33.3 (4)	0-87.0 (5)	0-50.0 (4)	--	0-36.8 (2)
Others	0-28.6 (6)	0-20.0 (6)	0-100 (10)	0-8.3 (2)	--	0-22.1 (1)
Dominant species	*Lumbrineris longifolia* *Paraprionospio* sp. *Prionospio ehlersi* *Sigambra tentaculata* *Theola lubrica*	*Lumbrineris longifolia* *Paraprionospio* sp. *Prionospio ehlersi* *Sigambra tentaculata* *Theola lubrica*	*Lumbrineris longifolia* *Paraprionospio* sp. *Theola lubrica*	*Lumbrineris longifolia* *Paraprionospio* sp. *Theola lubrica*	*Lumbrineris longifolia* *Paraprionospio* sp.	*Lumbrineris longifolia* *Paraprionospio* sp. *Sigambra tentaculata* *Theola lubrica*

* Located near the mouth of the Ota River (to the east and west), respectively.
** Located in Edajima Bay.
† Located in Kure Bay (northern, middle, and southern sections, respectively).
†† Values given represent the range and the average (in parentheses).

Imabayashi (1983) investigated the Hiuchi-Nada and Harima-Nada Seas and reported that there was a strong correlation between the number of species and the number of individuals in the benthos (its diversity index) and dissolved oxygen in the bottom water, which suggests that the anoxic water mass caused the change in the macrobenthos.

Table 2 shows the environmental factors at each observation station in the innermost part of Hiroshima Bay. In the center of Kure Bay, the average DO was almost the same as at the other observation stations. However, the lowest DO was lower than the other stations, and the sulfide concentration rate and DO consumption were higher. This could be the reason for the accumulation of organic matter in the sediment and the occurrences of anoxic water mass that caused the poor-condition benthos.

Anoxic Water Mass in Kure Bay, 1986

Figure 12 shows the variation of vertical profiles of water temperature during the period July 4-October 27, 1986. The difference in water temperature between the upper and lower water layers reached about 10° C in mid-August; in October, the temperatures were consistent. In contrast, the surface water with highest temperature, 26° C, at observation station 7 (St. 7) in southern Kure Bay, was noticeable compared with St. 4 in the northern part of the bay.

Salinity decreased in the upper water layer in mid-July because of heavy rain, and the same trend was recognized at the other observation stations (Figure 13).

According to the results of the investigation by the Third District Port Construction Bureau of the Transportation Ministry (1986), in Kure Bay, the ebb tide in the upper water flows out from the northern bay or the channel of Hayase; in the bottom water, it flows in at the southern bay and flows out from the northern bay. The flood tide in the upper and bottom water flows to the opposite direction to the ebb tide. The subtidal tide flows in at the channel and flows out from the northern bay. At St. 7 in the southern bay, the salinity in the sediment is higher than the other observation stations because of the inflow of water from the open sea through the Hayase channel.

The DO distribution in the bottom water in Kure Bay is shown in Figure 14. Anoxia could be recognized on July 4 and was the most serious from August 6, when the bedding water developed. On October 7, when the stratification of the water temperature and the salinity vanished, the anoxia in the midbay was quite high.

Primary Causes of Anoxia and Countermeasures

A schema of the DO balance and the primary causes of the anoxic water mass is shown as Figure 15. The anoxic water mass seems to originate from the seashore in northern Hiroshima Bay, but the anoxia is more pronounced in Kure Bay. The wind-driven surface flow, which was reported in Mikawa Bay (Aichi Prefecture Fisheries Experimental Station 1973, 1974) and in Tokyo Bay in 1986, cannot occur easily in Kure Bay. In addition, the subtidal current in

TABLE 2. SUMMARY OF ENVIRONMENTAL FACTORS, INNER HIROSHIMA BAY

Item	St. 1	St. 2	St. 3	St. 4	St. 7	St. 10
DO in the bottom water* (mg/ℓ)	2.0–9.1 (6.3)	3.1–9.0 (5.9)	1.8–10 (6.6)	1.6–10 (5.5)	1.1–10 (5.5)	1.6–10 (5.7)
Ignition loss in sediment** (%)	10–12 (11)	9.4–13 (10)	10–13 (12)	10–12 (12)	10–15 (12)	10–12 (11)
Sulfide in sediment** (mg/g dry)	0.10–0.48 (0.33)	0.12–0.73 (0.31)	0.24–1.0 (0.61)	0.16–0.56 (0.40)	0.85–1.3 (1.0)	0.10–0.83 (0.50)
DO consumption in sediment† ($g/m^2/day$)	0.82	0.57	1.64	0.49	2.45	0.42

Note: Station locations are described in Table 1. Values given are the range and the average (in parentheses).

* Results of monthly observations, May 1985–February 1986 and May 1986–February 1987.

** Results of four season observations, May 1985–February 1986 and May 1986–February 1987.

† Results of laboratory experiment with surface sediment sampled in 1984.

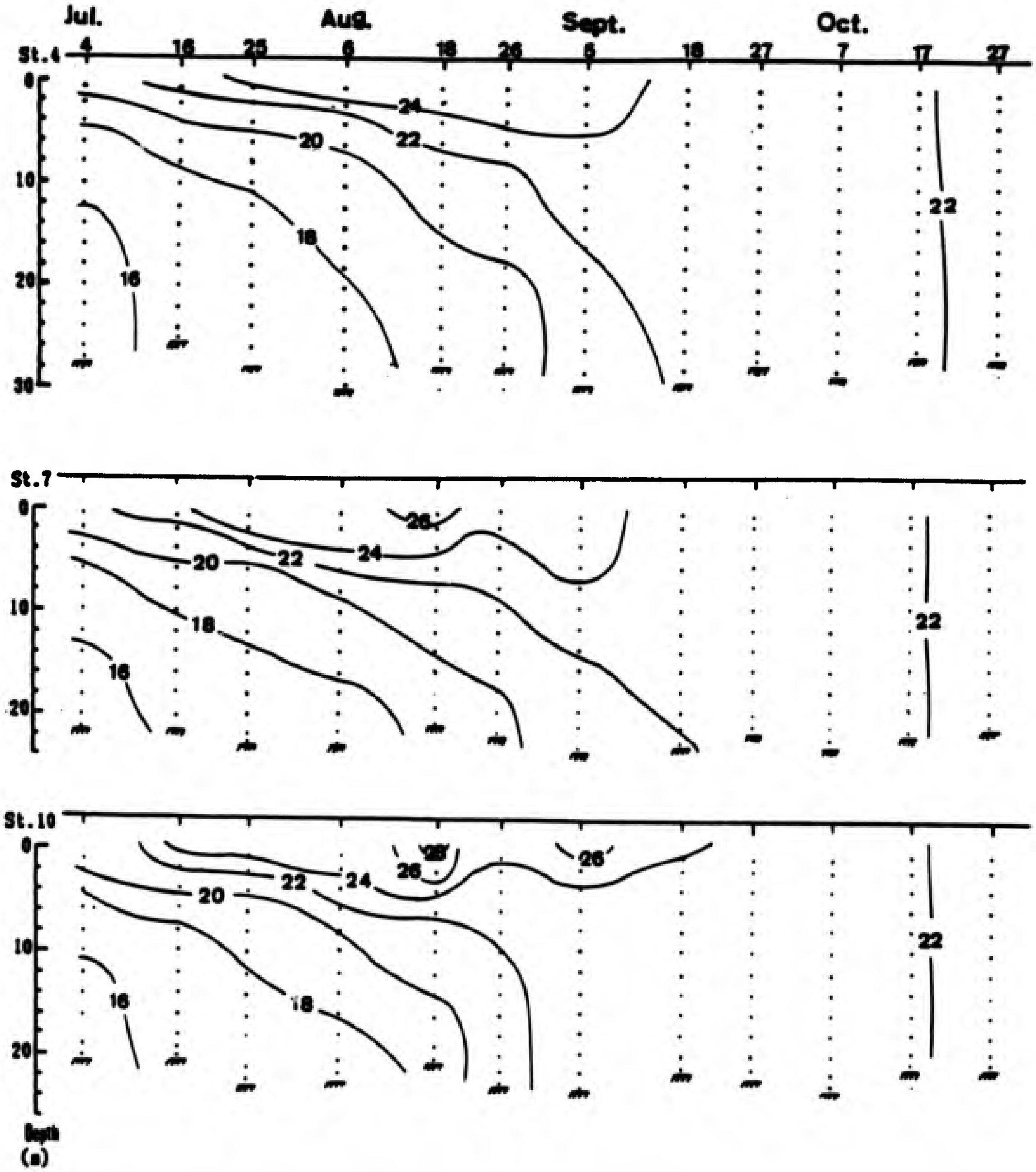


Figure 12. Variation of vertical profiles of temperature (degrees Centigrade) in Kure Bay, July 4-October 27, 1986

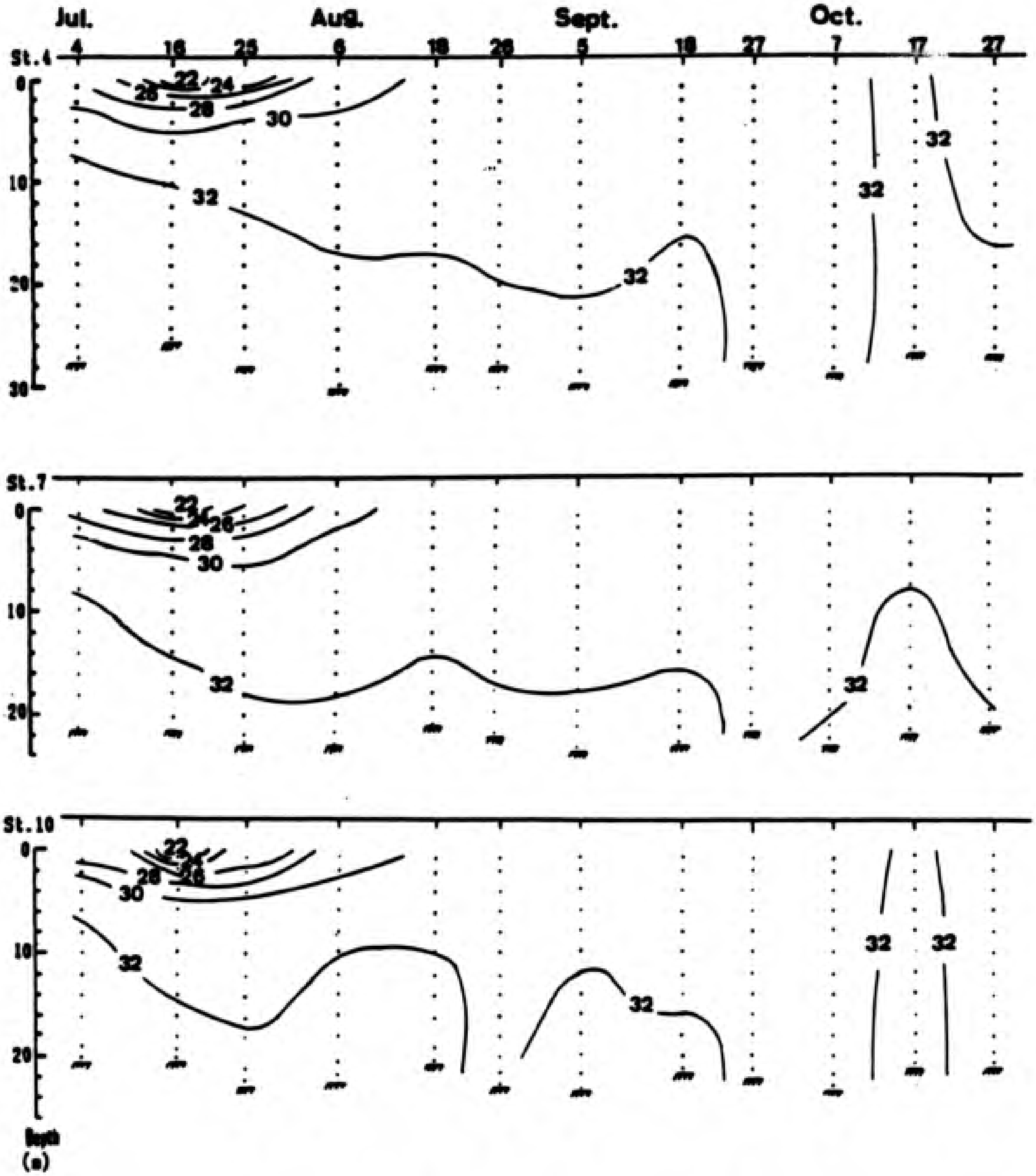


Figure 13. Variation of vertical profiles of salinity (percent) in Kure Bay, July 4-October 27, 1986

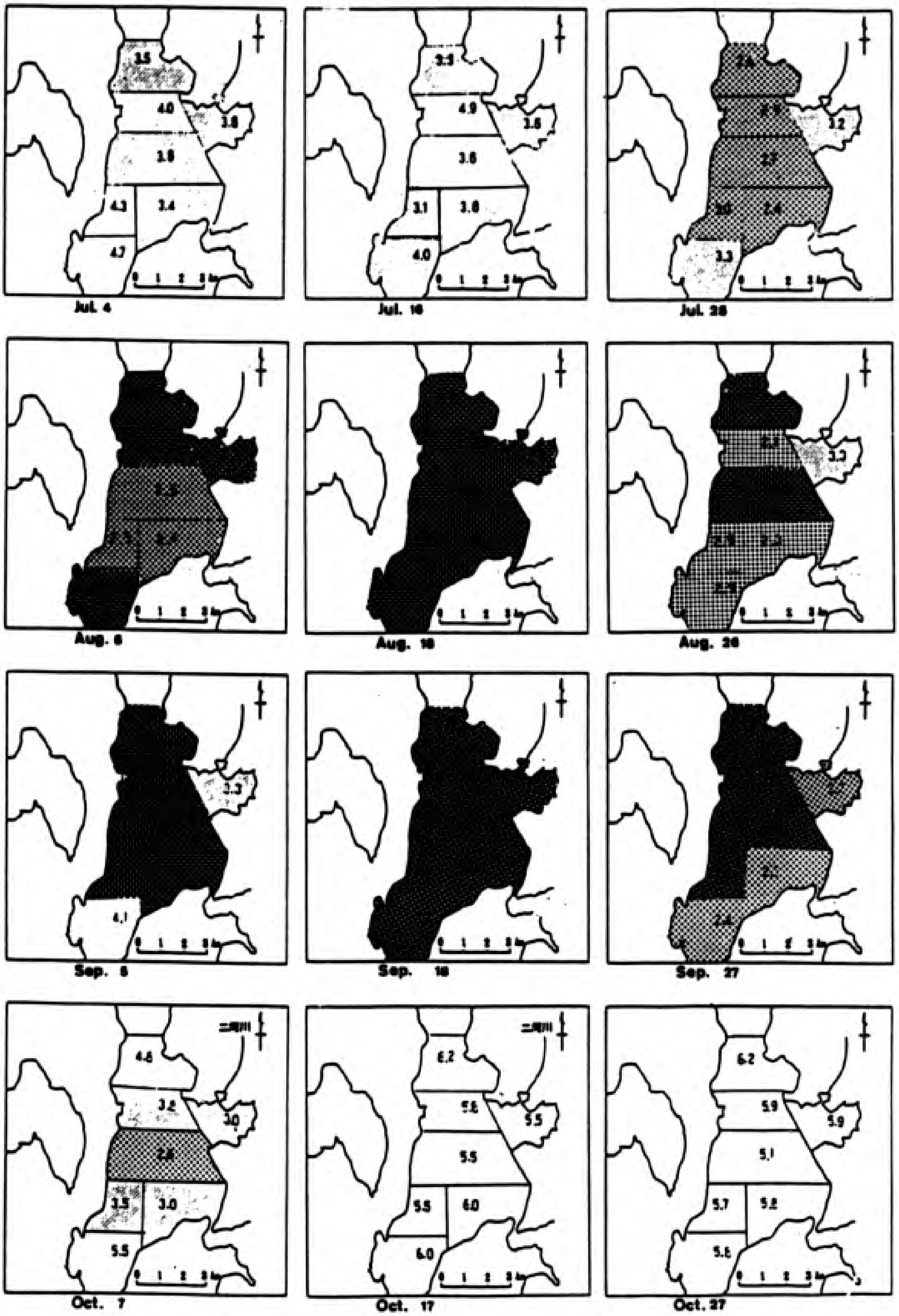
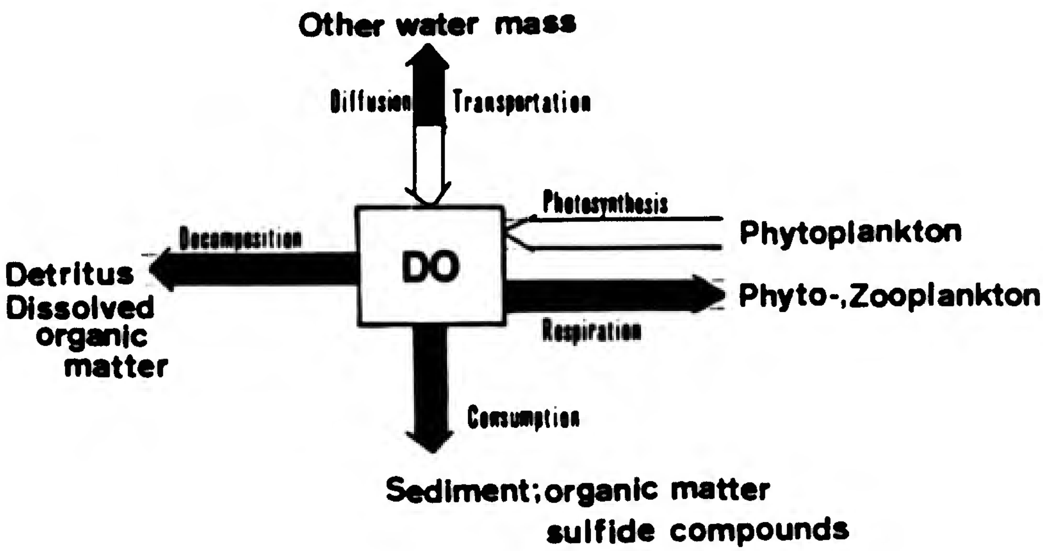
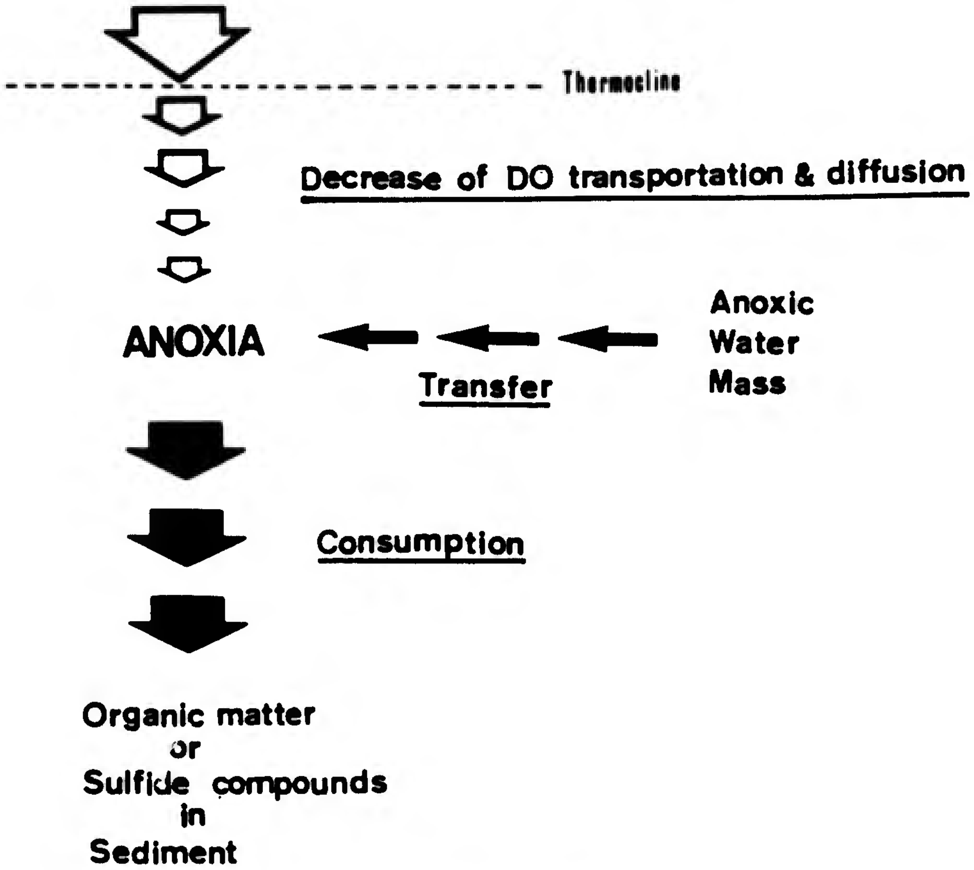


Figure 14. Distribution of DO in bottom water of Kure Bay, July 4-October 27, 1986



a. Dissolved oxygen balance



b. Causes of anoxia

Figure 15. Schema of anoxic water mass, Kure Bay

the bottom water in Kure Bay flows toward the north (Third District Port Construction Bureau of the Transportation Ministry 1986). Therefore, it was determined that the anoxic water mass in Kure Bay occurs within the bay.

The reduced oxygen supply in the upper water and the development of stratification are probably due to the strengthening of the stratification in Osaka Bay; however, in Hiuchi-Nada Sea, it is probably due more to the decreased oxygen supply because of the stagnated coldwater mass under the second thermocline than to the oxygen consumption in the sediment.

In Kure Bay, the anoxia is the most serious when the stratification becomes moderate, and that means the reduced oxygen supply does not cause the occurrence of the anoxic water mass daily. The consumption of oxygen in the sediment in Kure Bay was measured as 2 g O_2 per square metre per day, which is higher than the value for Hiuchi-Nada Sea (0.5 g O_2 per square metre per day (Ochi and Takeoka 1986), which has a great influence on the occurrence of the anoxic water mass. Because the temperature of the bottom water was the highest in late September, water temperature probably accelerates DO consumption.

As a result of this study it was concluded that the occurrence of the anoxic water mass in Kure Bay is greatly affected by the accumulation of organic pollutant in the sediment, which also contributed to a depauperate benthic community. Thus, the most effective way to reduce the anoxic water mass is to decrease and control the accumulation of organic pollutants in the sediment. This will be very important for the long term.

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