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Morphology and Ecology of Four Types of the Genus *Paraprionospio* (Polychaeta: Spionidae) in Japan

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Abstract

Well-known eutrophic indicator species, *Paraprionospio pinnata* (EHLERS, 1901) was studied morphologically and ecologically in Japan. This species in Japan can be divided into the four types (A, B, CI, CII) on the basis of the external morphology, areal distribution and habitat preference. They are recognized as discrete species respectively. The filament at the base of the third branchia, pigment spots on the peristomium, transverse dorsal crests, ventral bilobed ridge on setiger 8, adult body size and so on, which were hardly or not used previously, serve for the morphological classification. Type A is a species restricted in inshore waters shallower than 20m in water depth. Type B is an inland sea mud or muddy sand bottom species. Type CI is an eurytopic species widely distributed in various environment. Type CII is an offshore waters species. Only types A and B are useful for eutrophic indicators. These two types do not have an opportunistic nature. Type A has a good adaptation to eutrophic environments in regard to both physiological tolerance and the timing of the settlement. Type B chiefly depends on physiological tolerable ability for the prosperity in eutrophic areas.

Contents

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I Introduction

In Japan, *Paraprionospio pinnata* (EHLERS, 1901) was known as the only species which belonged to the genus *Paraprionospio* (OKUDA, 1937; IMAJIMA and HARTMAN, 1964). Many workers studied this species because it was frequently dominant and conspicuous in benthic communities of the enclosed bays.

MIYADI, MASUI and their colleagues carried out the benthic surveys in many bays, and reported that a large number of *P. pinnata* were collected in Beppu Bay (MIYADI, 1941a), Ise Bay (MIYADI, 1941b), Yamakawa Harbor in Kagoshima prefecture (MIYADI and MASUI, 1942a), Nanao Bay in Ishikawa prefecture (MIYADI and MASUI, 1942b), Tokyo Bay (MASUI, 1943), Habu Harbor in Izuoshima (MIYADI et al., 1943) and Uranouchi Bay in Kochi prefecture (MIYADI et al., 1944a). On the basis of these synecological studies, MIYADI et al. (1944b) concluded that *P. pinnata* was one of the typical species which lived in the area with middle embayment degree. Embayment degree is the synthetical index showing the intensity and the type of embayment factors, and is divided into three stages, namely, weak, middle and strong (MIYADI et al., 1944b).

KITAMORI (1969) showed that *P. pinnata* could be utilized for the indicator species of organic pollution from the macrobenthic investigations in Tokyo Bay, Osaka Bay and Ise Bay. Subsequently, some other workers also used this species as a pollution indicator (JOH et al., 1969, 1978a; KAWABE, 1975; SANUKIDA et al., 1979, 1981). RICHARDSON (1971) and BOESCH (1973) refered to high tolerance to organic pollution in *P. pinnata.* SIMON and DAUER (1977) reported that *P. pinnata* occurred dominantly after the defaunation due to red tide in Tampa Bay, Florida.

As mentioned above, *P. pinnata* seems to be usually distributed in enclosed bays polluted by organic wastes. However, *P. pinnata* was sometimes recorded also in unenclosed waters. For example, KITAMORI (1973) and TAKAHASHI and ISHIKAWA (1976) reported that considerable relative dominance of *P. pinnata* was observed in the open sea coast off the industrial cities. They connected the appearance of the species with local accumulation of organic pollutants below the surf zone, but the pollution load of such localities are much less than those in the enclosed bays. Furthermore, TAMAI

(1981) and YOKOYAMA and TAMAI (1981) found the four different types belonging to the genus *Paraprionospio* in Japan, which were distinguished each other by their external morphology and environmental preference. Those findings suggest that the species which has been named *P. pinnata* traditionally in Japan might be separated into several discrete species or comparable taxa. Therefore, the ecological characteristics including life history and the utility as the biological indicators of organic pollution must be also investigated separately in every different morphological type.

Recently, in Osaka Bay (TAMAI, 1982) and Kumihama Bay in Kyoto prefecture (YOKOYAMA, 1982), the life history of *Paraprionospio* sp. (type A) has been studied and the reasons for the prosperity of the type in eutrophic environments have been discussed. UENO and YAMAMOTO (1982) have studied the tolerance to temperature and salinity in *Paraprionospio* sp. (type A).

In this paper, I will describe the morphology, distribution and life history of the four types belonging to *Paraprionospio* in Japan. Furthermore, I will also discuss the utility for environmental indicators of these types and the reason for their prosperity on the basis of their ecological data, the physico-chemical environmental conditions and macrobenthic community structures. Some parts of this paper have already been published (TAMAI, 1981, 1982; YOKOYAMA and TAMAI, 1981).

II Morphological features of the four types of *Paraprionospio*

In Japan, *P. pinnata* (EHLERS, 1901) was known as the only species which belonged to *Paraprionospio* (OKUDA, 1937; IMAJIMA and HARTMAN, 1964). However, the author (TAMAI) and YOKOYAMA have independently found that *Paraprionospio* specimens in Japan are composed of four morphologically different types (TAMAI, 1981; YOKOYAMA and TAMAI, 1981). The morphology of these all types coincides with the original description of *P. pinnata* (EHLERS, 1901), however, they are different one another in detailed morphology as described below. But, it is impossible to identify these four types because the characters treated by us have been almost ignored in the previous morphological studies and even the previous descriptions of *P. pinnata* are taxonomically confused (YOKOYAMA and TAMAI, 1981). Therefore, these four types were provisionally named type A, type B, type CI and type CII. In this section, their morphological features are described briefly according to TAMAI (1981) and YOKOYAMA and TAMAI (1981). Please refer to YOKOYAMA and TAMAI (1981) for further details.

Fig. 1 and Table 1 show the morphology of the four types and the comparison among them. Each type has well-developed peristomial wings and three pairs of pinnate branchiae beginning on the setiger 1. These are generic characters of *Paraprionospio*. Consequently, these four types apparently belong to this genus. The characters peculiar to type A are the bifoliate branchial lamellas (Fig. 1, d), first appearance site of nonlimbate capillaries in neuropodia (Fig. 1, e) and the transverse dorsal crests on setigers 21-35 (Fig. 1, b). Especially, the dorsal crests are the conspicuous morphological features observed with ease. Type B is characterized by the ventral bilobed ridge on

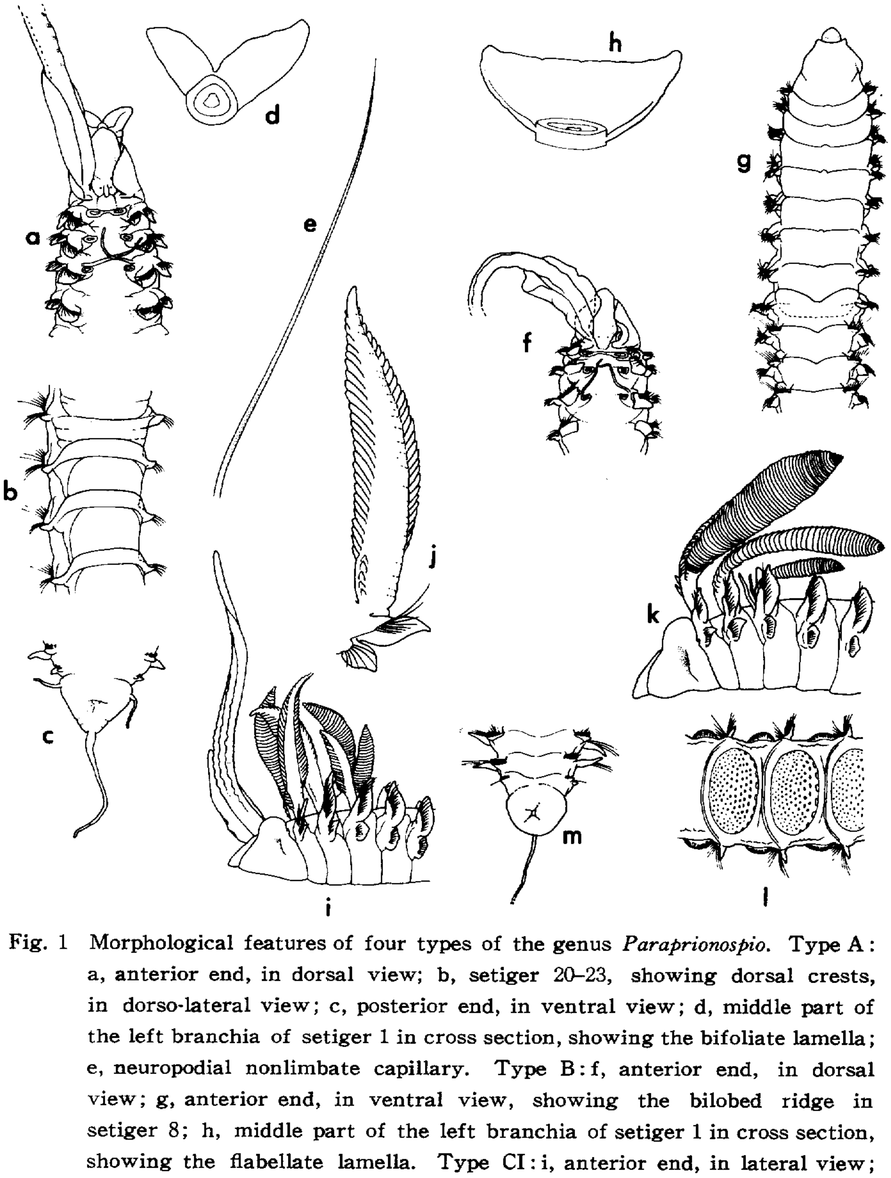


Fig. 1 Morphological features of four types of the genus *Paraprionospio*. Type A: a, anterior end, in dorsal view; b, setiger 20–23, showing dorsal crests, in dorso-lateral view; c, posterior end, in ventral view; d, middle part of the left branchia of setiger 1 in cross section, showing the bifoliate lamella; e, neuropodial nonlimbate capillary. Type B: f, anterior end, in dorsal view; g, anterior end, in ventral view, showing the bilobed ridge in setiger 8; h, middle part of the left branchia of setiger 1 in cross section, showing the flabellate lamella. Type CI: i, anterior end, in lateral view; j, first parapodium with branchia, in anterior view. Type CII: k, anterior end, in lateral view; 1, setigers 21–23, in dorsal view, showing transparent dorsal cuticle and interramal pouches; m, posterior end, in ventral view (YOKOYAMA and TAMAI, 1981).

Table 1 Comparison of four types of the genus *Paraprionospio* (YOKOYAMA and TAMAI, 1981)

Characters	Type A	Type B	Type CI	Type CII
Pigment spots on the peristomium	absent	absent	present	present
Papilla on the posterior margin of the peristomium	present	absent	present	present
Shape of the lamellar plate of the branchia	bifoliate	flabellate	flabellate	flabellate
Accessory lamellae on the first branchia	absent	absent	present	present
Filament at the base of the third branchia	present	present	absent	present
First appearance of nonlimbate capillaries in neuropodia	setiger 10	setiger 9	setiger 9	setiger 9
Ventral bilobed ridge on setiger 8	absent	present	absent	absent
Transverse dorsal crests between the notopodia	present on setigers 21–35	absent	absent	absent
Transparent dorsal cuticle	present on setigers 21–35	present on setigers 21–36	absent	present on setigers 21–31
Interramal pouches	absent	usually present	present or absent	present
Lateral anal cirri	present	present	present	absent

Table 2 Maximum specimens of four types of the genus *Paraprionospio*

Types		Max. weight (mg)	Max. length (mm)	Max. width* (mm)	Max. No. of setigers
A	Osaka Bay	64.5	53.0	1.76	98
	Tosa Bay	230.9	88.1	2.40	113
B		20.3	37.0	1.30	94
CI		112.5	76.0	1.80	111
CII		135.8	67.2	2.05	96

*The width of the fifth setiger excluding parapodia was measured.

setiger 8 (Fig. 1, g) and the small adult size (Table 2). Type CI resembles type CII in the presence of peristomial pigment spots (Fig. 1, i, k), the branchial shape (Fig. 1, i, j, k), size of the adult specimen (Table 2) and so on. However, type CII is distinguished from type CI by the presence of a filament at the base of the third branchia (Fig. 1, k) and the transparent dorsal cuticles (Fig. 1, l), and the absence of the lateral annal cirri (Fig. 1, m).

III Distribution of the four types of *Paraprionospio*

III-1 Methods

Surveys were carried out 33 times in the six areas shown in Fig. 2——Osaka Bay, Hiuchi-nada, Beppu Bay, Kii Channel, Tosa Bay and East China Sea——from July 8-10,

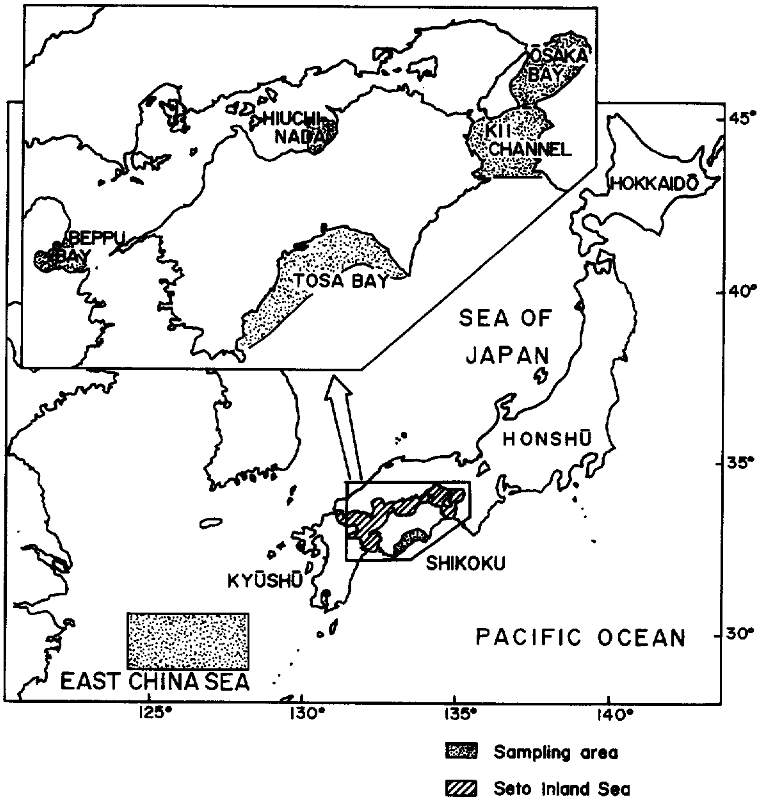


Fig. 2 Map showing the sampling areas.

1975 to June 23-24, 1981. One to five bottom samples were collected at each station using Smith-McIntyre grab sampler (covering area $0.1m^2$). Physico-chemical factors usually measured were as follows: temperature, salinity and dissolved oxygen in surface and bottom waters; temperature, total carbon content, total nitrogen content and grain size composition in sediments. Salinity was measured by salinometer, and dissolved oxygen measured by EIL 1520 DO meter or Winkler's method. Sediments of the top 2-3cm were used for analyses. Total carbon content and total nitrogen content were determined by Yanagimoto MT 500 CN corder. Coarse particles were removed from sediment by 1mm mesh sieve and the remaining fine sediment was used for the measurement of total carbon and nitrogen content. Mud content, namely, weight percentage of the silt-clay component, was used for the expression of the results of grain size analysis. Macrobenthic animals were sieved off from sediment with 1mm mesh, or both 0.5mm and 1mm mesh sieves, and fixed with formalin. In this chapter, only the specimens obtained with 1mm mesh were usually used to describe the distribution of *Paraprionospio* and the benthic community structure. 0.5mm mesh samples will be used in the next chapter.

III-2 Distribution

In this section, the relation between the distribution of *Paraprionospio* and five fundamental factors—water depth, mud content and total nitrogen content in sediment, number

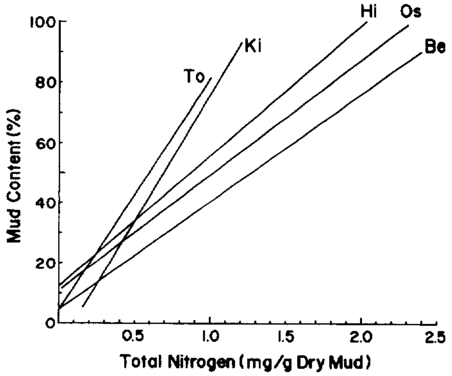


Fig. 3 Relation between total nitrogen and mud content in sediment.

Osaka Bay (Os): $MC=38.0TN+11.6$ $(r=0.82,\ n=142)$

Hiuchi-nada (Hi): $MC=43.2TN+12.2$ $(r=0.91,\ n=49)$

Beppu Bay (Be): $MC=35.5TN+4.8$ $(r=0.91,\ n=39)$

Kii Channel (Ki): $MC=84.0TN-8.5$ $(r=0.89,\ n=22)$

Tosa Bay (To): $MC=76.0TN+5.0$ $(r=0.56,\ n=60)$

MC; mud content, TN; total nitrogen, r; correlation coefficient, n; the number of samples.

All regression equations are significant ($P<0.001$).

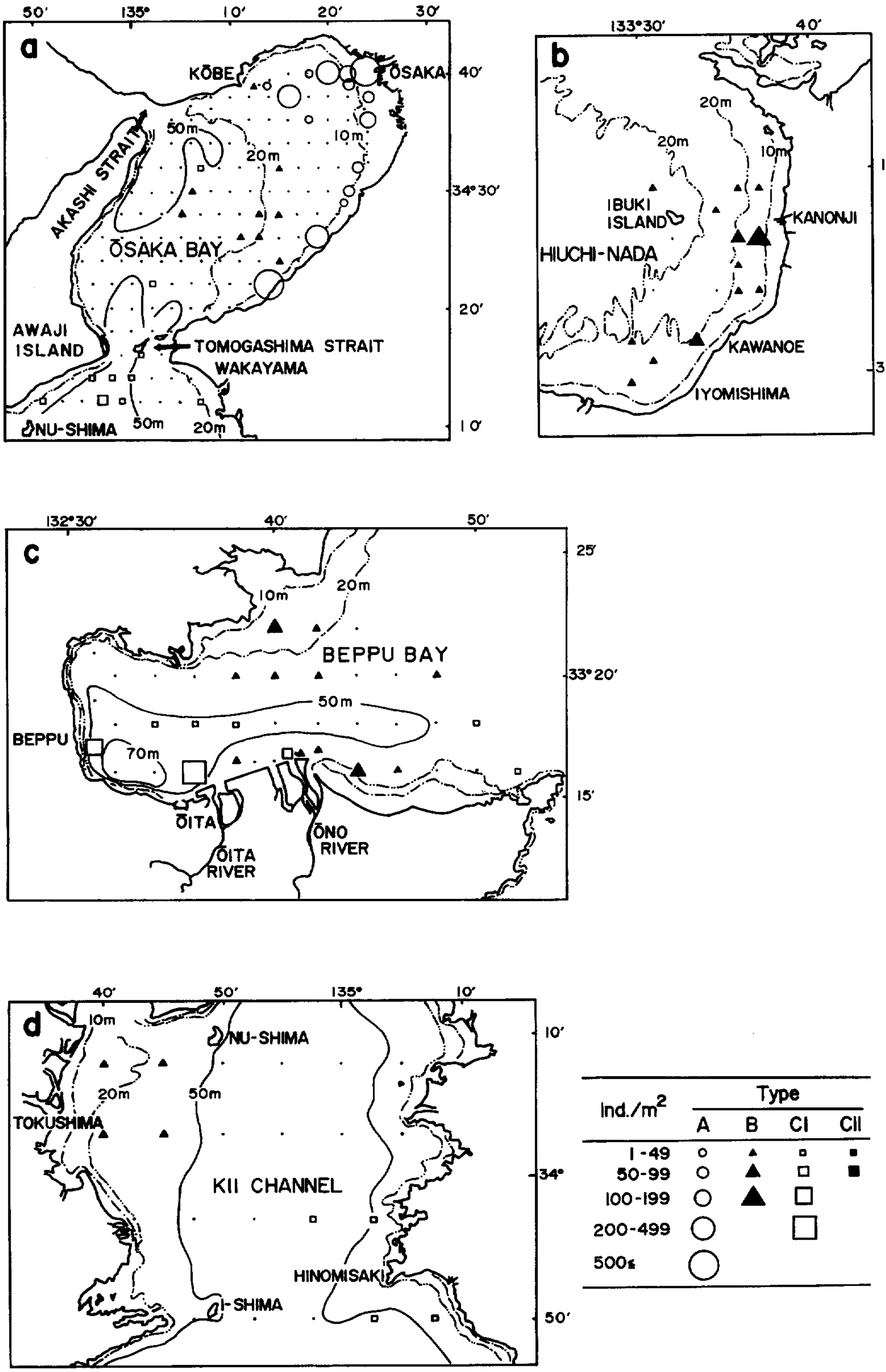
Table 3 Sampling data of the genus *Paraprionospio*

Surveyed area	Date	No. of samplings	surveyed depth range (m)	No. of collected specimens				Distributional depth range (m)				Sediments*1			
				A	B	CI	CII	A	B	CI	CII	A	B	CI	CII
OsakaBay	Dec. 8–13, '76	89	10–117	875*2	10	4		10–20	14–51	45		MS–M	M	MS	
	June 20–July 4, '77	148	6–93	521	11	17		7–18	14–48	15–64		GS–M	M	S–MS	
Hiuchi-nada	Aug. 4–5, '77	32	11–24		3				10–22.5				MS–M		
	June 6–7, '78	40	14–26		4				16				M		
	Aug. 28–29, '78	44	13–23		6				13.5–23				MS–M		
	Nov. 30, '78	24	9–24		96				20–24				M		
	May 27–28, '79	36	12–26		65(18)*3				13–26				M		
	Aug. 22–23, '79	36	12–24		33				14–24				MS–M		
	Dec. 13–14, '79	17	10–24		37(50)				10–24				MS–M		
	June 11–12, '80	18	14–24		30(25)				14–24				MS–M		
	Aug. 31–Sept. 1, '80	18	8–23		5(2)				12–22				MS–M		
	Feb. 3–5, '81	16	10–25		122(35)				13–25				MS–M		
	June 23–24, '81	18	11–24		106(51)				14.5–23				MS–M		
Beppu Bay	Nov. 30–Dec. 2, '75	51	18–74		48	69			26–54	26–60			M	M	
	July 2–4, 76	76	15–72		39	294			15–46	37–58			MS–M	S–M	
	Nov. 29–30, '77	76	8–72		33	16			20–53	8–27			M	MS	
Kii Channel	June 12–13, '76	22	20–86		4	5			20–42	38–67			M	S–MS	
Tosa Bay	Nov. 17–20, '75	70	20–312				21				56–98				MS
	June 3–12, '76	52	22–110			38	37			24–110	40–89			S–MS	MS
	Feb. 16–17, '77	17	15–50	79		8	9	15		15–50	50	S		S–MS	MS
	June 13–14, '77	22	15–50	142		17	2	15		15–45	35–50	S		S–MS	MS
	Oct. 12–13, '77	22	15–50	67		3	7	15		25	50	S		S	MS
	Apr. 25, 78	11	5–70	14		9	7	10–15		15–70	35–70	S		S–MS	MS
	June 27, '78	20	5–70	21		7	10	10–15		15–70	35–70	S		S–MS	MS
	Aug. 23, '78	20	5–70	318		4	2	10–15		15–70	45–70	S		S–MS	MS
	Oct. 24, '78	20	5–70	42			9	10–15			35–70	S			MS
	Dec. 18 '78	20	5–70	219(10)		(1)	22(4)	15		35	35–70	S		MS	MS
	Mar. 6, '79	20	5–70	27		4	18	15		15–45	25–70	S		S–MS	S–MS
	Apr. 26, '79	18	5–80	9		1	13(1)	15		45	35–80	S		MS	MS
	June 22, '79	18	5–80	57		4(1)	10	15		25–80	35–80	S		S–MS	MS
	Nov. 29, '79	18	5–80	17(5)		1	1(3)	15–25		70	70–80	S		MS	MS
	Feb. 7, '80	18	5–80	9	1		17(1)	15	45		45–80	S		MS	MS
East China Sea	July 8–10, '75	18	52–118		1	1			70	52			MS	MS	
Total		1145		2417(15)	654(181)	502(2)	185(9)								

*1 GS; gravelly sand. M; mud. MS; muddy sand or sandy mud. S; sand.

*2 Number of specimens retained on 1mm sieve.

*3 Figure in parenthesis shows number of the small specimens which passed through 1mm sieve and retained on 0.5 mm sieve.


a
50′
135°
10′
20′
30′
40′
34°30′
20′
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KŌBE
ŌSAKA
AKASHI STRAIT
50m
20m
10m
ŌSAKA BAY
AWAJI ISLAND
TOMOGASHIMA STRAIT
WAKAYAMA
NU-SHIMA
50m
20m
b
133°30′
40′
10′
34°
20m
20m
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IBUKI ISLAND
KANONJI
HIUCHI-NADA
KAWANOE
IYOMISHIMA
c
132°30′
40′
50′
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33°20′
15′
10m
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BEPPU BAY
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ŌITA
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40′
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NU-SHIMA
TOKUSHIMA
KII CHANNEL
HINOMISAKI
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Type
A
B
CI
CII
1-49
50-99
100-199
200-499
500≤

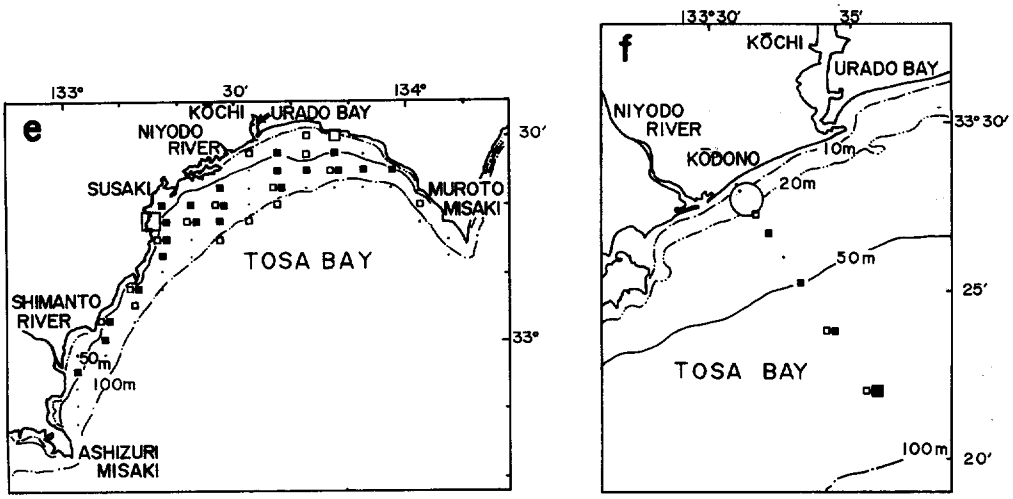

Fig. 4 Distribution of *Paraprionospio*.
a; Osaka Bay from June 20 to July 4, 1977.
b; Hiuchi-nada on May 27–28, 1979.
c; Beppu Bay on July 2–4, 1976.
d; Kii Channel on June 12–13, 1976.
e; Tosa Bay on June 3–12, 1976.
f; off Kōdono in Tosa Bay on June 22, 1979.

of species and density of macrobenthic animals—was investigated. In general, macrobenthic distribution has been known to be largely influenced by these physico-chemical and biological factors (Miyadi et al., 1944b; Sanders, 1958; Kitamori, 1963; Rhoads and Young, 1970; Rhoads, 1974; Tsuchiya and Kurihaka, 1976; Nakao, 1982 etc.). Water depth is undoubtedly one of the most important factors affecting the distribution of marine organisms. Mud content indicates hydrographical conditions. Total nitrogen content is the indicator of organic materials in sediment which are used for the food of surface and subsurface deposit feeders. Mud content and total nitrogen content in sediment were directly related but the relation between them was rather different in each area (Fig. 3). The pooling of the regression equations was possible only between Tosa Bay and Kii Channel ($P<0.05$). So mud content and total nitrogen content should be treated separately. Number of species and density were used for the description of the benthic communities. The outline of the sampling data of *Paraprionospio* are summarized in Table 3. Fig. 4 shows the distribution of *Paraprionospio* in each surveyed area and Figs. 5–7 show the relation between the distribution and the five factors. The relation between water depth and mean density of the four types of *Paraprionospio* is shown in Table 4. The seasonally fluctuating factors, such as temperature, salinity, dissolved oxygen, will be mainly dealed with in the next chapter.

General description of the surveyed areas

Osaka Bay: This bay is located at the eastern part of the Seto Inland Sea. The bay is almost enclosed by Honshu and Awaji Island and has an elliptical outline. The northeastern half of the bay is shallower that 20m, and the bottom slope is descending gradually toward the Akashi and Tomogashima Straits. All area but nearshore and strait regions is mainly covered with mud. JOH et al. (1978a, b) have reported that in the northeastern part of the bay the organic pollution of sediment is conspicuous except the quite shallow nearshore region and oxygen deficiency in the bottom water occurs in summer, while in the southwestern part the sediment is nearly normal and the oxygen deficiency occurs only weakly.

Hiuchi-nada: This area is nearly central part of the Seto Inland Sea. In this study the eastern part of Hiuchi-nada was surveyed, where very flat mud bottom of about 20m in depth develops. Marked organic polluion is observed in this area (OKAICHI et al., 1971) and the oxygen deficiency in the bottom water happens in summer stratification (YANO, 1977; OCHI et al., 1978).

Beppu Bay: This bay is situated at the western part of the Seto Inland Sea and has rectangular outline. Depth of the bay mouth is about 40m. The innermost part of the bay reaches more than 70m in depth, and forms a small basin-like depression. Almost all area of the bay is covered with mud, but the bay mouth is covered with sand or muddy sand. In the area more than 60m in depth, the dissolved oxygen deficiency occurs fairly strongly at least from July to November (SHIOZAWA et al., 1977), and this influences macrobenthic community structure (TAMAI, 1980).

Kii Channel: The northern part of the Kii Channel connects with Osaka Bay by the Tomogashima Strait and with Harima-nada by the Naruto Strait. The southern part of this channel opens to the Pacific Ocean and is influenced by the Kuroshio branch. The northwestern part, off Tokushima, is comparatively shallow and covered with mud. The other part is deep and sand or muddy sand bottom.

Tosa Bay: Tosa Bay opens to the Pacific Ocean widely and is semi-circular in outline. This bay is influenced by the Kuroshio strongly. Sediments change from sand to muddy sand with increasing water depth and mud content of the sediment is the highest at the depths of 60–90m. With further increase of the water depth, sediments again tends to become coarser (TAMAI, 1981).

East China Sea: Surveyed area is on the continental shelf of the northern part of East China Sea. The water depth ranged from 52m to 118m. The sediment consisted of sand or muddy sand.

Distribution

Type A: This type was collected in Osaka Bay and Tosa Bay. It mainly inhabits shallower than 20 m in depth (Fig. 4, Tables 3, 4) but the distribution is independent of the sediments and the benthic community structures (Figs. 5-7). Type A is a coastal waters species. The density became sometimes very high. It reached 1208 individuals per m^2 at the depth of 10-15m in Osaka Bay. The density in Tosa Bay was relatively low, which was 82 individuals per m^2 at the depth of 15-20m (Table 4).

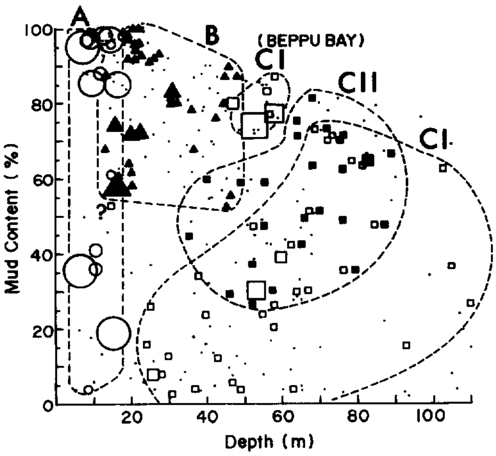

Fig. 5 Distribution of *Paraprionospio* in relation to water depth and mud content in sediment. This figure was drawn from the results of all surveys shown in Fig. 4.

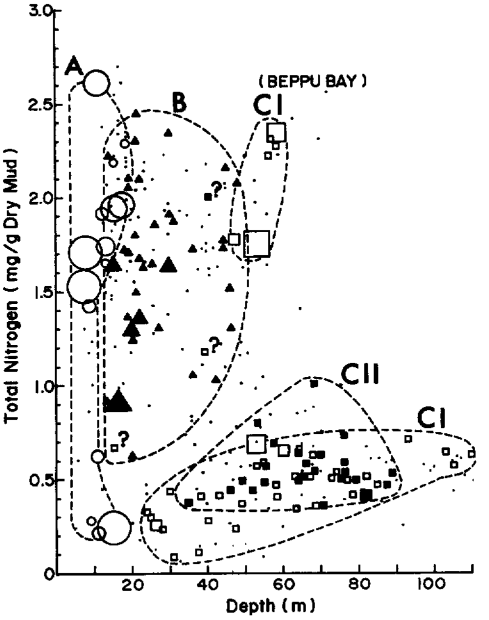

Fig. 6 Distribution of *Paraprionospio* in relation to water depth and total nitrogen in sediment. This figure was drawn from the results of all surveys shown in Fig. 4.

Table 4 Relation between water depth and mean density[*1] of four types of the genus *Paraprionospio*

Depth (m)	Number of individuals/m^2													
	Type A		Type B						Type CI					Type CII
	Osaka Bay	Tosa Bay	Osaka Bay	Hiuchi-nada	Beppu Bay	Kii Channel	Tosa Bay	East China Sea	Osaka Bay	Beppu Bay	Kii Channel	Tosa Bay	East China Sea	Tosa Bay
5- 10	434.4 (9)[*2]	0 (19)	0 (9)	0 (3)	0 (2)		0 (19)		0 (9)	75.0 (2)		0 (19)		0 (19)
10- 15	1208.1(68)	28.4 (19)	0.3(68)	10.9 (36)			0 (19)		0(68)			0 (19)		0 (19)
15- 20	90.4(77)	82.4(143)	5.8(77)	28.8 (53)	24.3 (7)		0(143)		0.1(77)	0 (7)		1.3(143)		0(143)
20- 30	0.2(94)	0.2(122)	6.0(94)	22.7(207)	10.4(25)	10.0 (2)	0(122)		0(94)	1.2(25)	0 (2)	3.4(122)		0.3(122)
30- 40	0(62)	0 (28)	3.7(62)		7.6(51)	3.3 (3)	0 (28)		0.6(62)	0.4(51)	6.7 (3)	2.1 (28)		7.1 (28)
40- 50	0(42)	0 (28)	1.0(42)		7.3(44)	2.5 (4)	0.4(28)		1.7(42)	5.9(44)	0 (4)	3.2 (28)		7.1 (28)
50-100	0(41)	0(205)	0.2(41)		0.8(74)	0(13)	0(205)	0.7(15)	2.2(41)	45.0(74)	2.3(13)	2.0(205)	0.7(15)	10.2(205)
100-	0 (1)	0 (42)	0 (1)				0 (42)	0 (3)	0 (1)			0.7 (42)	0 (3)	0 (42)
Total	(402)	(606)	(402)	(299)	(203)	(22)	(606)	(18)	(402)	(203)	(22)	(606)	(18)	(606)

[*1] Mean density was calculated from 1550 samples of 64 surveys from July 8-10, 1975 to July 8, 1981.

[*2] Figure in parenthesis shows number of samplings by Smith-McIntyre grab sampler with $0.1m^2$ in covering area.

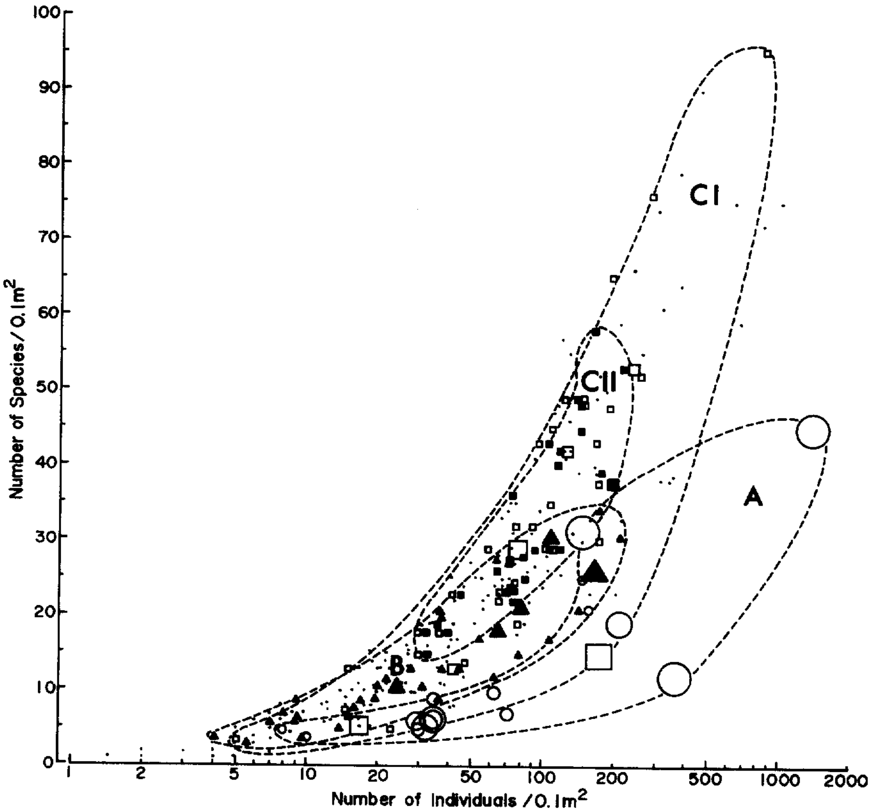

Fig. 7 Distribution of *Paraprionospio* in relation to two factors of benthic communities (number of the individuals and number of the species). This figure was drawn from the results of all surveys shown in Fig. 4.

Type B: This type was collected in all six surveyed areas but extremely rare in Tosa Bay and East China Sea (Table 3). In Hiuchi-nada, only type B was widely distribued on the organic-rich mud or muddy sand bottom and the other three *Paraprionospio* species were not sampled at all. The distributional bottom conditions of type B in Osaka Bay, Beppu Bay and Kii Channel are similar to that in Hiuchi-nada. This type is almost completely restricted to mud or muddy sand bottom containing fairly high organic matter content in inland sea region and is rarely collected in offshore waters or on sand bottom (Figs. 4-6, Table 3). In the distributional area of this type, the density of macro-benthic animals and the number of species were low or moderate (Fig. 7). The density of this type was somewhat low (Table 4).

Type CI: This type was collected in Osaka Bay, Beppu Bay, Kii Channel, Tosa Bay and East China Sea (Fig. 4, Table 3). In many cases, this type was distributed on organic-poor muddy sand or sand bottom, such as Tomogashima Strait, bay mouth of Beppu Bay, Tosa Bay, but was also collected on organic-rich mud bottom in innermost part of Beppu Bay (Figs. 5, 6). Type CI is an eurytopic species which is able to be widely distributed in various water depth, sediments and benthic community structures. The density of this type was usually very low except the case of Beppu Bay (Table 4).

Type CII: Type CII is an offshore waters species, which was collected only in Tosa Bay and not collected in inland sea region at all (Fig. 4, Table 3). This type was almost distributed on muddy sand bottom with low organic matter content at depths deeper than 35m (Figs. 5, 6). Benthic fauna in the distributional area of this type was fairly rich (Fig. 7). The density of this type was low (Table 4).

The distributional characters of each type are summarized as Table 5.

Table 5 Comparison among the distributional area of four types of the genus *Paraprionospio*

	Type A	Type B	Type CI		Type CII
			innermost part of Beppu Bay	the others	
	coastal waters species	inland sea species	eurytopic species		offshore waters species
Distributional area	Osaka Bay (1396)*1	Osaka Bay (21)	Beppu Bay (332)	Osaka Bay (21)	Tosa Bay (194)
	Tosa Bay (1021)	Hiuchi-nada (688)		Beppu Bay (47)	
		Beppu Bay (120)		Kii Channel (5)	
		Kii Channel (4)		Tosa Bay (98)	
		Tosa Bay (1)		East China Sea (1)	
		East China Sea (1)			
Depth range	shallower than 20m	10–54m	26–60m	8–110m	25–98m
Sediments*2	GS–M	MS–M	M	S–MS	MS
Organic matter content in sediments	low-high	moderate-high	high	low	low
Benthic community					
Density	low-high	low-moderate	low-moderate	moderate-high	moderate
Number of species	low-high	low-moderate	low	moderate-high	moderate-high

*1 Number of the collected specimens

*2 See Table 3

IV Life history of the four types of *Paraprionospio* and seasonal changes in benthic community

In this chapter, oceanographic environment and benthic community structure were studied seasonally in Osaka Bay, Hiuchi-nada and Tosa Bay. The life history of the four types of *Paraprionospio* were also investigated in these areas. Osaka Bay and Hiuchi-nada are inland sea areas and Tosa Bay is an open bay strongly influenced by the Kuroshio. The life history of type A was investigated in Osaka Bay and Tosa Bay. The life history of type B was investigated in Osaka Bay and Hiuchi-nada. The life histories of types CI and CII were examined in Tosa Bay.

IV-1 Methods

Sampling areas were shown in Fig. 8. The surveys in Osaka Bay were carried out fifteen times throughout the year from April 18, 1979 to March 9, 1980. Five sampling

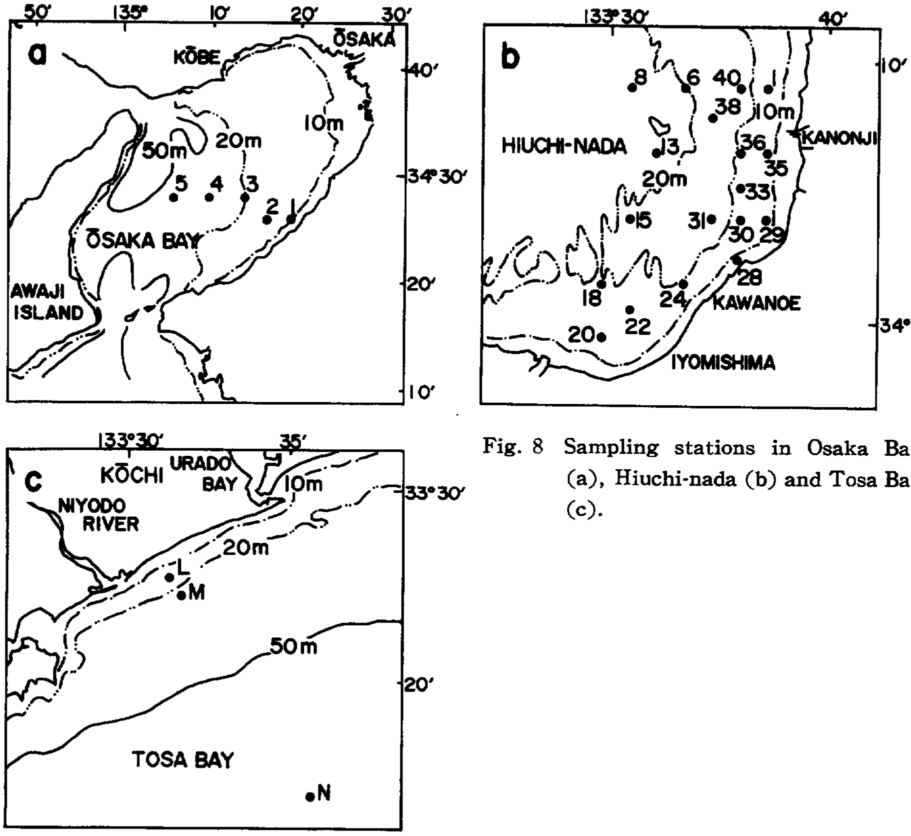

Fig. 8 Sampling stations in Osaka Bay (a), Hiuchi-nada (b) and Tosa Bay (c).

stations, Stns. 1-5 were arranged in order of water depth. The depth of each station was 10m, 15m, 20m, 28m and 39m. The surveys in Hiuchi-nada were carried out eleven times throughout about four years from August 4-5, 1977 to June 23-24, 1981. The depth range of sampling stations was 8-26m. The surveys in Tosa Bay were carried out twenty nine times throughout longer than the four years from February 16-17, 1977 to July 8, 1981 at Stns. L and M, and twenty times throughout longer than the two years from April 26, 1979 to July 8, 1981 at Stn. N. The water depths were 15m at stn. L, 25m at Stn. M and 80m at Stn. N.

Physico-chemical factors usually measured were as follows: temperature, salinity and dissolved oxygen in both surface and bottom water; temperature, total carbon content, total nitrogen content, ignition loss and mud content in sediment. Ignition loss was estimated from the loss of weight on ignition at 850°C for 1 hour of dried sediment samples from which coarse particles were previously removed by 1mm mesh sieve. The methods for measurement of the other environmntal factors are as described in chapter III.

Smith-McIntyre grab sampler was used to collect macrobenthic animals and sediments.

In Osaka Bay, three samples were taken at Stn. 1 and two samples at the others. In Hiuchi-nada, one to five samples were collected at each station. In Tosa Bay, two to five samples were collected at each station. Collected samples were sieve by a 1mm mesh sieve, and the animals retained on the sieve were fixed by formalin. 0.5mm mesh was also put under 1mm mesh to collect the juveniles of *Paraprionospio* effectively in May 27-28, 1979 and after December 13-14, 1979 in Hiuchi-nada, and after December 18, 1978 in Tosa Bay. The density of macrobenthic animals and the percentage composition of *Paraprionospio* were calculated from the specimens collected with 1mm mesh sieve.

The most convenient parameter of worm size is the body width since many worms were incomplete due to the loss of rear end during collection. Width of the fifth setiger excluding parapodia of all worms, and total length, wet weight and number of setigers of some complete worms were measured. All *Paraprionospio* specimens collected were used for size frequency analyses regardless of the sieve mesh sizes to collect benthic animals.

Presence of the gametes in coelom was examined microscopically. The total number of eggs per worm was estimated by the following procedures. All eggs in coelom of the complete female fully suspended in 50cc of tap water, and three subsamples of 1cc were taken. The number of eggs in each subsample was counted under a microscope, and the mean value obtained from the three subsamples was used to calculate the total number of eggs per worm. No complete females of type B containing eggs were obtained, so the total number of eggs of this type could not be calculated. Egg diameter was shown by the mean value of the longest and shortest diameter measured using a microscope with a micrometer. The diameter of twenty eggs per female was measured and five females were examined per survey, if possible. Namely, the diameter of one hundred eggs per survey was usually measured.

The brief ecological observations of type A were carried out in the laboratory. Type A for this observation was collected at Stn. L in Tosa Bay in February 9, 1982. The worms were reared in acrylic tube of 40mm in diameter and 200mm in length containing the sediment and the sea water of sampling station. They were observed under the aeration and temperature regulation.

IV-2 Seasonal changes in bottom environments and benthic community structures

Osaka Bay

Bottom environments: Fig. 9 shows the seasonal changes in temperature, salinity and dissolved oxygen in bottom water at Stns. 1-5. The minimum temperatures were 7. 3-9.1°C from February to March and the maximum temperatures reached 23.5-24.8°C from August to September. The salinity ranged from 31.25 to 33.83‰ at all stations throughout the year, slightly influenced by fresh water. The salinity was somewhat higher in warm season than in cold season. The dissolved oxygen concentration became low in varying extent during June to September at all stations. At Stns. 1-2, dissolved oxygen content fell below 40% in saturation from August to September, at Stn. 3 it was more than 50% except in early June showing 43%, and at Stns. 4-5 it was more than 60% throughout the year. In this area, the dissolved oxygen concentration became high

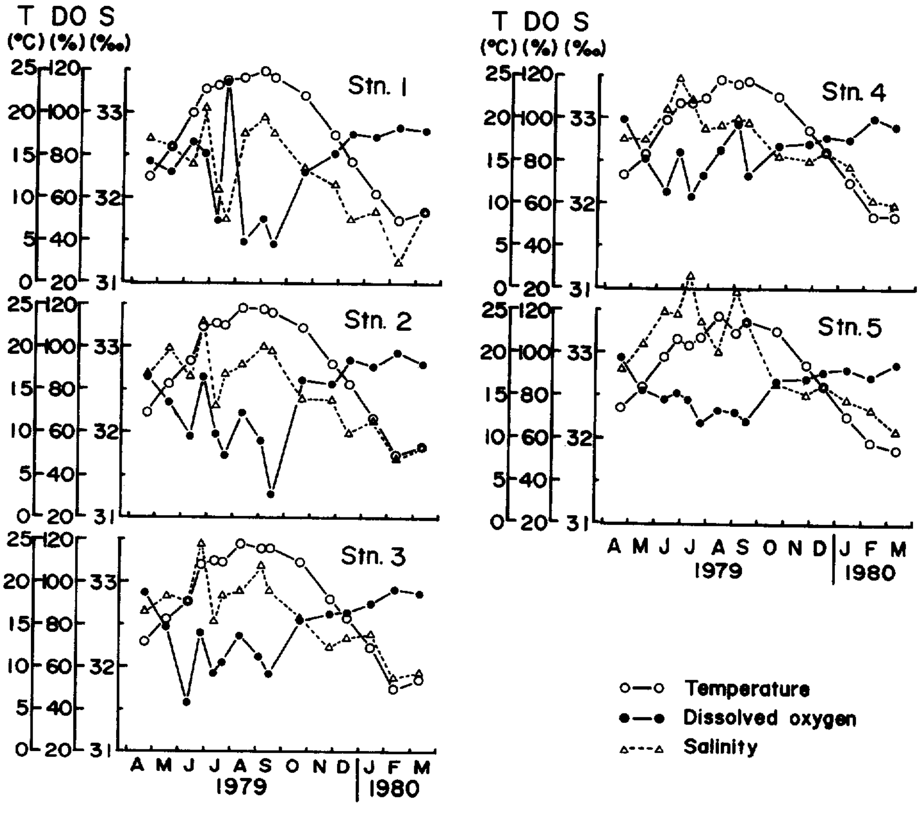

Fig. 9 Seasonal changes in temperarure, dissolved oxygen and salinity in bottom water in Osaka Bay from April 18, 1979 to March 9, 1980.

Table 6 Physico-chemical characters of sediments collected at stations 1–5 in Osaka Bay on March 9, 1980.

Station	Total carbon (mg/g dry mud)	Total nitrogen (mg/g dry mud)	Ignition loss (%)	Mud content (%)
1	2. 77	0. 30	2. 7	10. 9
2	21. 17	2. 23	11. 3	98. 8
3	22. 65	2. 17	11. 2	98. 8
4	17. 34	1. 48	8. 8	75. 5
5	18. 58	0. 99	7. 6	47. 3

with increasing water depth.

Physico-chemical characters of sediments are presented in Table 6. The bottom of Stn. 1 was occupied mainly by sand, shell and gravel with a small amount of organic matter, because of the influence of wave action. On the contrary, the bottom of Stns. 2-3 was almost completely occupied by the organic matter-rich, soft mud. This fact suggests that water currents above the bottom are very gentle. The bottom of Stns. 4-5 was covered with muddy sand. The organic matter content showed the moderate value.

On the basis of the nature of bottom water and sediment described above, these five stations can be divided into three groups, namely, Stn. 1, Stns. 2-3 and Stns. 4-5.

Table 7 Annual means of density and number of species of the macrobenthic animals at stations 1-5 in Osaka Bay from April 18, 1979 to March 9, 1980.

A) Density

Taxonomic group	Stn. 1		Stn. 2		Stn. 3		Stn. 4		Stn. 5	
	Ind./m^2	%	Ind./m^2	%	Ind./m^2	%	Ind./m^2	%	Ind./m^2	%
Polychaeta	5756	90.7	357	89.1	54	61.4	142	53.0	168	59.7
Crustacea	107	1.7	10	2.4	11	12.6	10	3.6	18	6.5
Echinodermata	57	0.9	7	1.8	9	10.3	14	5.2	39	13.7
Mollusca	218	3.4	21	5.2	10	11.1	86	32.1	32	11.2
Others	211	3.3	6	1.5	4	4.6	16	6.1	25	8.9
Total	6349		401		87		269		282	

B) Number of species

Taxonomic group	Stn. 1		Stn. 2		Stn. 3		Stn. 4		Stn. 5	
	No./0.1m^2	%	No./0.1m^2	%	No./0.1m^2	%	No./0.1m^2	%	No./0.1m^2	%
Polychaeta	18.8	65.1	6.4	71.0	3.5	62.1	6.9	57.2	8.3	62.9
Crustacea	2.5	8.6	0.5	5.2	0.6	11.6	0.9	7.8	1.3	10.1
Echinodermata	0.5	1.9	0.4	4.8	0.5	9.8	1.0	8.3	1.1	8.1
Mollusca	3.0	10.6	1.1	12.3	0.7	12.8	1.9	16.1	1.3	9.8
Others	4.0	13.8	0.6	6.7	0.2	3.7	1.3	10.6	1.2	9.1
Total	28.8		9.0		5.5		12.0		13.2	

Benthic community: Density, number of species and their seasonal changes are shown in Table 7 and Fig. 10. Seasonal changes in main component species of each station are shown in Fig. 11 and Appendix table 1.

At Stn. 1, number of species and density of the benthic animals were the highest of all five stations. Polychaetes were numerically most abundant. There were two peaks of the density of benthic animals, one is from June to July and the other from

September to October. The lower density was found from November to April. The peak from June to July was composed of the polychaetes *Euchone* sp., *Pseudopolydora* sp., amphipod *Corophium acherusicum* and so on, and the next peak was composed of two dominant polychaete species, *Paraprionospio* sp. (type A) and *Cirriformia tentaculata*. Polychaetes *Lumbrineris longifolia*, *Sigambra tentaculata* and *Glycinde* sp. were fairly abundant and common throughout the year. Number of species was very

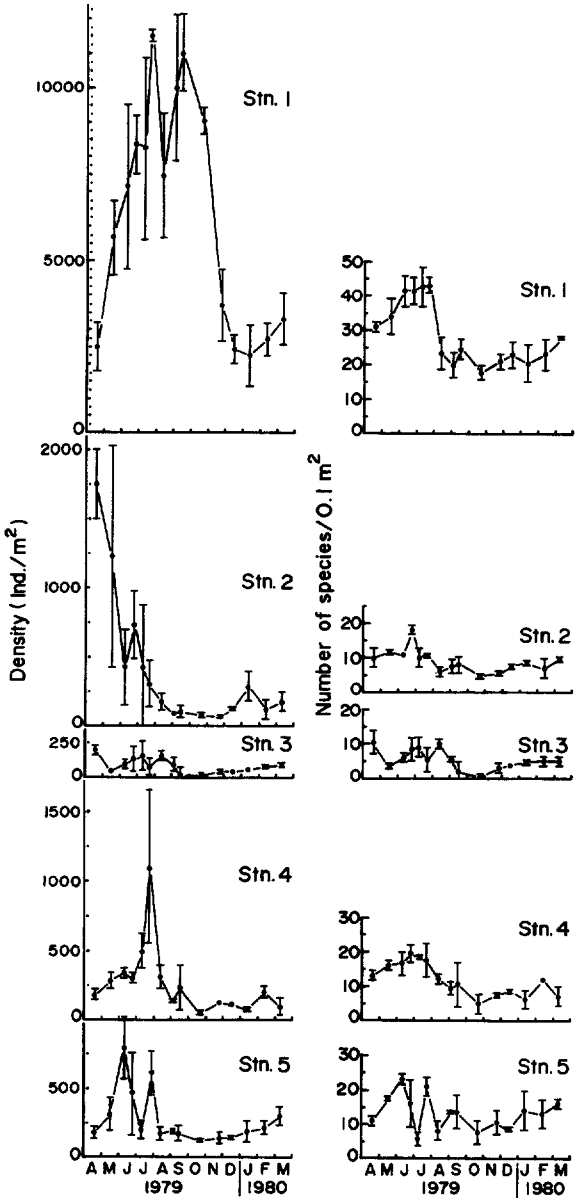

Fig. 10 Seasonal changes in density and species number of macrobenthic animals in Osaka Bay from April 18, 1979 to March 9, 1980. Closed circle shows mean value and vertical bar shows standard deviation.

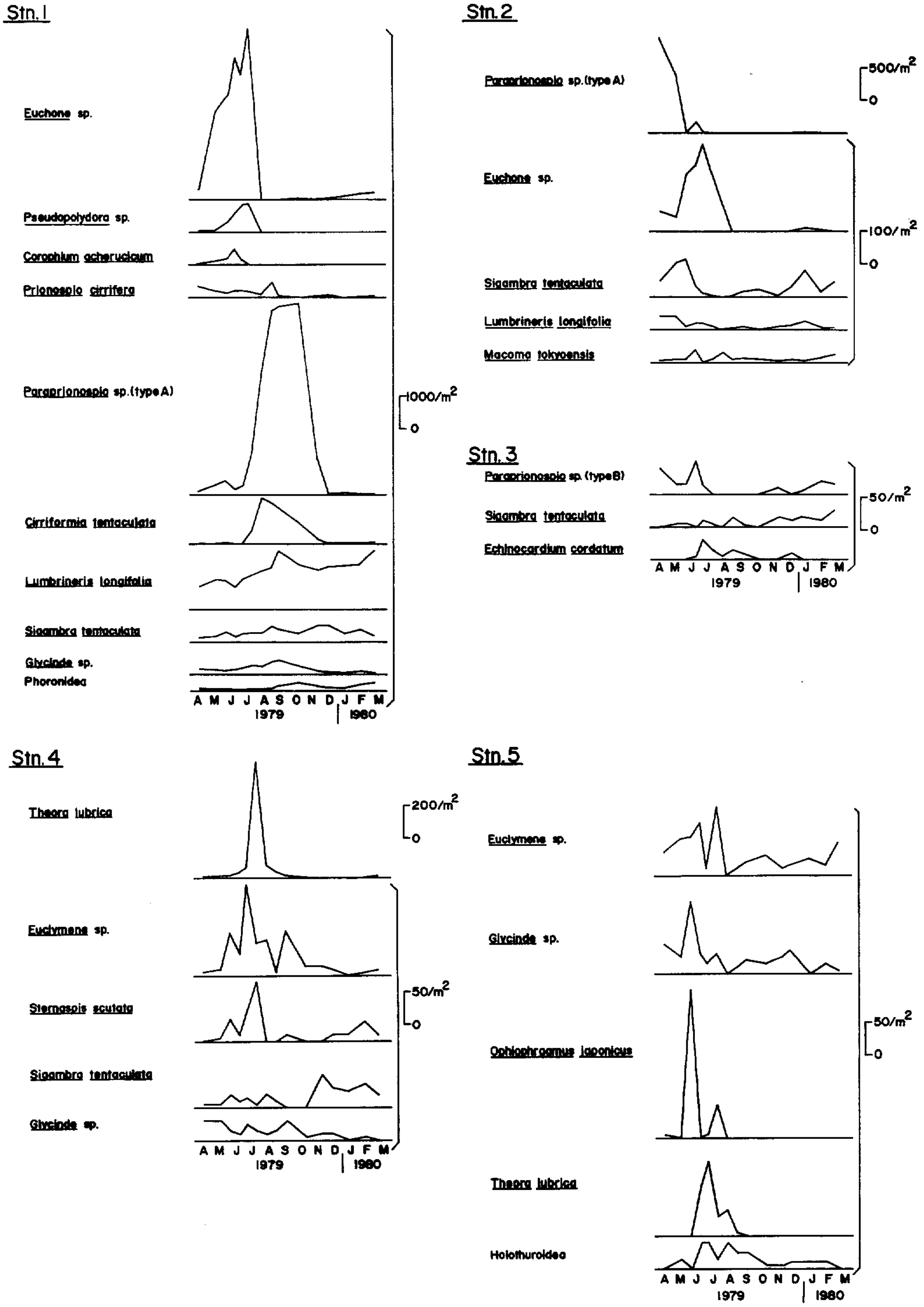

Fig. 11 Seasonal changes in density of numerically abundant species in Osaka Bay from April 18, 1979 to March 9, 1980.

high during early June to late July, and immediately after, the rapid decrease of species number followed.

Stn. 2 is characterized by the dominant occurrence of *Paraprionospio* sp. (type A). Type A occupied about half of the total number of specimens collected at Stn. 2. Density of the benthic animals was high in spring, and low in fall. This spring peak was composed of type A. Number of species was slightly high from spring to summer and low in fall. Annual mean number of species was low.

Benthic fauna of Stn. 3 was very poor. Number of species and density of benthic animals were slightly high from spring to summer, and low in fall. Species collected more than 20 individuals were only two polychaete species, *Paraprionospio* sp. (type B) and *Sigambra tentaculata*.

Stn. 4 and Stn. 5 resemble each other in benthic structure. Density and number of species of both stations were 270-280 individuals per m^2 and 12-13 per $0.1m^2$ respectively, and they were high in summer and low in fall. The main component species of both stations were bivalve mollusc *Theora lubrica*, polychaetes *Euclymene* sp., *Sternaspis scutata*, *Sigambra tentaculata* and *Glycinde* sp..

Hiuchi-nada

Bottom environments: As the bottom water and sediments in this area change with water depth, this area was conveniently divided into two parts by the 15m depth contour. Environmental factors showing the remarkable change with water depth were dissolved oxygen in bottom water and several sediment factors (Table 8). Oxygen deficiency in bottom water was conspicuous at the depth more than 15m. The mean dissolved oxygen in saturation at the depth more than 15m fell below 40% in August, while in the shallower region it was maintained above 70%. The sediment factors such as mud content, total nitrogen content and total carbon content were all high on

Table 8 Physico-chemical characters of bottom water and sediments in Hiuchi-nada.

	Water depth (m)	Range or mean ± standard deviation	
Dissolved oxygen (%)	-15	71.7±22.8 (August)	107.2±11.3 (the others)
	15-	37.5±18.7 (August)	100.7±15.6 (the others)
Salinity (‰)	-15	32.31±0.08	
	15-	32.47±0.17	
Mud temperature (°C)	-15	8.1 (February)−25.9 (August)	
	15-	8.9 (February)−24.9 (August)	
Total carbon (mg/g dry mud)	-15	9.18±4.69	
	15-	16.91±2.77	
Total nitrogen (mg/g dry mud)	-15	0.63±0.31	
	15-	1.80±0.37	
Mud content (%)	-15	31.9±22.7	
	15-	78.9±17.0	

mud bottom deeper than 15m in depth. The bottom shallower than 15m was occupied by sand or muddy sand, and the values of each sediment factor were low.

Benthic community: Density and number of species are shown in Table 9, their seasonal changes shown in Fig. 12, and seasonal changes in main component species shown in Table 10.

At the depth shallower than 15m, density and number of species were much higher than in the deeper region. Polychaete and crustacean were numerically abundant groups. High density and high percentage composition in density of crustacean were mainly caused by the large number of amphipod *Corophium* sp. specimens in June 6-7, 1978.

Table 9 Means of density and number of species of the macrobenthic animals in Hiuchi-nada from August 4-5, 1977 to June 23-24, 1981.

A) Density

Taxonomic group	Shallower than 15m		Deeper than 15m	
	Ind./m²	%	Ind./m²	%
Polychaeta	1339	52.7	140	54.8
Crustacea	805	31.7	7	2.5
Echinodermata	153	6.0	11	4.2
Mollusca	190	7.5	92	35.5
Others	53	2.1	8	3.0
Total	2540		258	

B) Number of species

Taxonomic group	Shallower than 15m		Deeper than 15m	
	No./0.1m²	%	No./0.1m²	%
Polychaeta	18.1	70.0	4.3	63.6
Crustacea	2.4	9.4	0.5	6.4
Echinodermata	1.0	3.8	0.4	5.0
Mollusca	2.6	10.0	1.3	18.4
Others	1.7	6.8	0.5	6.6
Total	25.8		7.0	

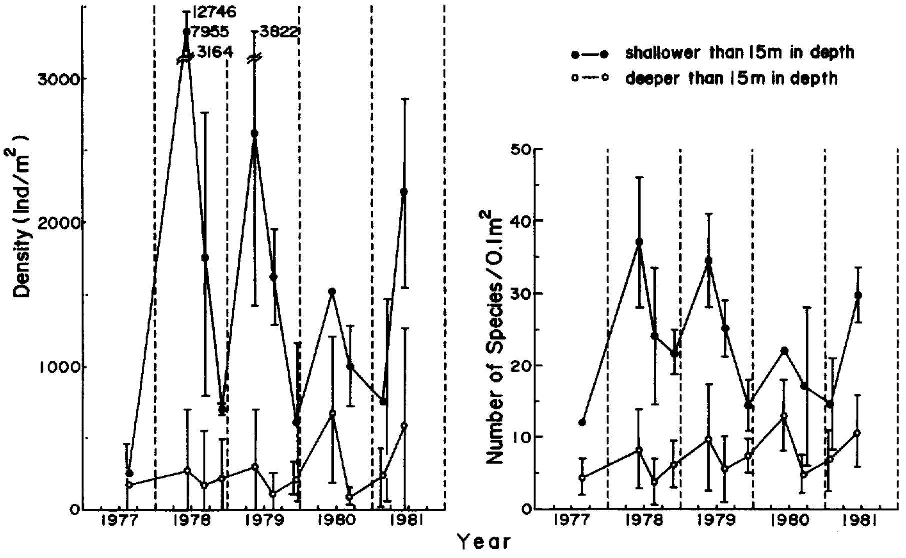

Fig. 12 Seasonal changes in density and species number of macrobenthic animals in Hiuchi-nada from August 4-5, 1977 to June 23-24, 1981. Closed and open circles show mean value and vertical bar shows standard deviation.

Table 10 Density (Ind./m²) of numerically abundant species in Hiuchi-nada from August 4–5, 1977 to June 23–24, 1981.

Region	Rank	Scientific name	Taxonomic group	1977	1978			1979			1980		1981		Mean	Cumulative Percentage
				Aug. 4, 5	June 6, 7	Aug. 28, 29	Nov. 30	May 27, 28	Aug. 22, 23	Dec. 13, 14	June 11, 12	Aug. 31 Sept. 1	Feb. 3–5	June 23, 24		
15m>	1	*Corophium* sp.	Cr		4840.0	27.8		12 5	3.3						444.0	23.35
	2	*Lumbrineris longifolia*	P	70.0	260.0	641.0		587.5	591.7	225.0	480.0	490.0	305.0	353.3	364.0	42.49
	3	*Lygdamis* sp.	P		756.7	176.7		392.5				46.7			124.8	49.05
	4	*Theora lubrica*	M	10.0	196.7			290.0	35.0		200.0	6.7		376.7	101.4	54.38
	5	*Prionospio ehlersi*	P		18.3	12.2		122.5	65.0	95.0	460.0	20.0	90.0	163.3	95.1	59.38
	6	Ophiuroidea sp.	E		603.3	44.4		90.0	1.7			93.3			75.7	63.36
	7	*Praxillella affinis*	P		91.7	323.3	30.0	105.0	218.3		10.0			23.3	72.9	67.19
	8	*Raeta rostralis*	M		26.7						20.0			423.3	42.7	69.44
	9	Nemertinea sp.	N	10.0	48.3	4.4	100.0	35.0	30.0	20.0	20.0	23.3	25.0	66.7	34.8	71.27
	10	*Notomastus* sp.	P	40.0	46.7	47.8		17.5	30.0	75.0	10.0		20.0	6.7	26.7	72.67
	11	*Sigambra tentaculata*	P		28.3	21.1		42.5	36.7	15.0	30.0	16.7		36.7	20.6	73.75
	12	*Nephtys Polybranchia*	P	30.0	15.0	8.9	5.0	27.5	1.7		100.0	3.3		26.7	19.8	74.79
	13	*Pseudopolydora* sp.	P		13.3	6.7			6.7	10.0	20.0	6.7	20.0	126.7	19.1	75.79
	14	*Poecilochaetus japonicus*	P		11.7	11.1	5.0	52.5	43.3	30.0		13.3	30.0	3.3	18.2	76.75
	15	Holothuroidea sp.	E	10.0	8.3			12.5	151.7			3.3		6.7	17.5	77.67
	16	*Harmothoe imbricata*	P		115.0	1.1		62.5				13.3			17.4	78.59
	17	*Euchone* sp.	P		65.0			10.0		5.0				110.0	17.3	79.50
	18	*Lagis bocki*	P		170.0			12.5							16.6	80.37
	19	*Chaetozone* sp.	P		1.7	64.4		2.5			10.0	23.3	65.0	13.3	16.4	81.23
	20	*Tharyx* sp.	P		30.0	57.8		40.0	3.3			36.7			15.3	82.03
		(*Paraprionospio* sp. (type B))	P	10.0		2.2		12.5	1.7	5.0	10.0	10.0	25.0	43.3	10.9	
15m≦	1	*Theora lubrica*	M	109.0	65.6	46.0	1.4	49.4	7.3	4.7	308.8	2.0	12.1	146.7	68.5	24.56
	2	*Paraprionospio* sp. (type B)	P	0.6	1.0	1.4	42.7	18.8	10.7	24.0	17.1	1.3	83.6	62.0	23.9	33.13
	3	*Raeta rostralis*	M					0.3			1.8			224.7	20.6	40.52
	4	*Lumbrineris longifolia*	P	9.0	42.6	64.3	6.4	9.4	5.7		56.5	4.0	5.7	2.7	18.8	47.26
	5	*Prionospio ehlersi*	P		3.8	0.3	29.5	25.3	9.3	6.0	57.6	0.7	33.6	8.0	15.8	52.93
	6	*P. cirrifera*	P		4.4	2.9	1.4	9.4	3.7	73.3	16.5	16.7	7.9	8.0	13.1	57.63
	7	*Sigambra tentaculata*	P	3.2	24.4	4.3	10.9	20.6	8.7	4 0	20.0	13.3	6.4	4.7	11.0	61.57
	8	*Sthenolepis yhleni*	P		1.0	1.4	7.3	13.4	1.3	36.7	20.0	5.3	8.6	1.3	8.8	64.73
	9	*Notomastus* sp.	P	18.7	20.5	9.1	10.9	11.6	6.0	3.3	3.5	3.3	6.4	1.3	8.6	67.81
	10	*Nephtys Polybranchia*	P	1.6	6.7	6.9	0.5	6.6	4.0	1.3	18.8		12.1	22.7	7.4	70.46
	11	*Pseudopolydora* sp.	P		2.6	0.6	46.4	0.6	0.7	4.0			5.7	20.0	7.3	73.08
	12	*Zeuxis squinjoreusis*	M	0.3	1.3	12.6	9.1	2.8	3.0	2.7	11.2	3.3	10.0	4.7	5.5	75.05
	13	Nemertinea sp.	N	1.9	8.5	0.9	2.3	8.4	2.0	6.7	10.6	2.7	5.0	10.0	5.4	76.99
	14	Holothuroidea sp.	E	9.7	4.6	2.3		35.6	2.7	2.7				0.7	5.3	78.89
	15	*Spiochaetopterus costarum*	P	2.9	3.1	0.6	20.5	3.8	3.0	8.0	1.8			2.0	4.2	80.40
	16	*Yokoyamaia ornatissima*	M		12.3	2.3		14.4		0.7	4.7	0.7	0.7	8.0	4.0	81.83
	17	*Poecilochaetus japonicus*	P		5.1	0.6		10.9	5.7		5.3			6.0	3.1	82.94
	18	*Micronephtys* sp.	P					1.6		0.7	27.6		3.6	0.7	3.1	84.04
	19	*Cossura coasta*	P					5.9	0.7		18.2	1.3		1.3	2.5	84.95
	20	Ophiuroidea sp.	E	10.0	1.0	0.9	0.9		6.7	0.7	5.3				2.3	85.77

Taxonomic groups are abbreviated as: Cr; Crustacea, E; Echinodermata, M; Mollusca, N; Nemertinea, P; Polychaeta.

Density and number of species were high during May to June and low during late summer to winter. *Corophium* sp., polychaetes *Lumbrineris longifolia* and *Lygdamis* sp. and mollusc *Theora lubrica* showed relatively high mean density greater than 100 individuals per m². Density of *Lumbrineris longifolia* was fairly stable and showed 225–640 individuals per m² except in August, 1977 and November, 1978. *Theora lubrica* and *Lygdamis* sp. were abundant in early summer, and were rare in fall and winter.

At the depths more than 15m, benthic fauna was poor. Density was one-fifteenth as high as at the depths less than 15m, and the number of species was about one-fourth. Numerically abundant animal groups were polychaete and mollusc. Seasonal changes in density and number of species in this region were very similar to those in shallower region. They were high during May to June, and low during summer to winter. *Theora lubrica*, *Paraprionospio* sp. (type B) and *Lumbrineris longifolia* were common in this region, but not abundant. Type B was the typical species which was more abundant on deep mud bottom than on shallow sand or muddy sand bottom. Such species were rare in this region.

Tosa Bay

Bottom environments: Fig. 13 shows the seasonal changes in temperature, salinity and dissolved oxygen concentration in bottom water. Temperature was fairly high and ranged from 14.7 to 26.9°C at Stn. L, from 14.9 to 26.0°C at Stn. M and from 16.1 to 22.2°C at Stn. N. Differences between minimum and maximum temperature at all stations were fairly small, especially the difference at Stn. N was only 6.1°C, which was half as large as those at Stns. L and M. Salinity showed high value ranging from

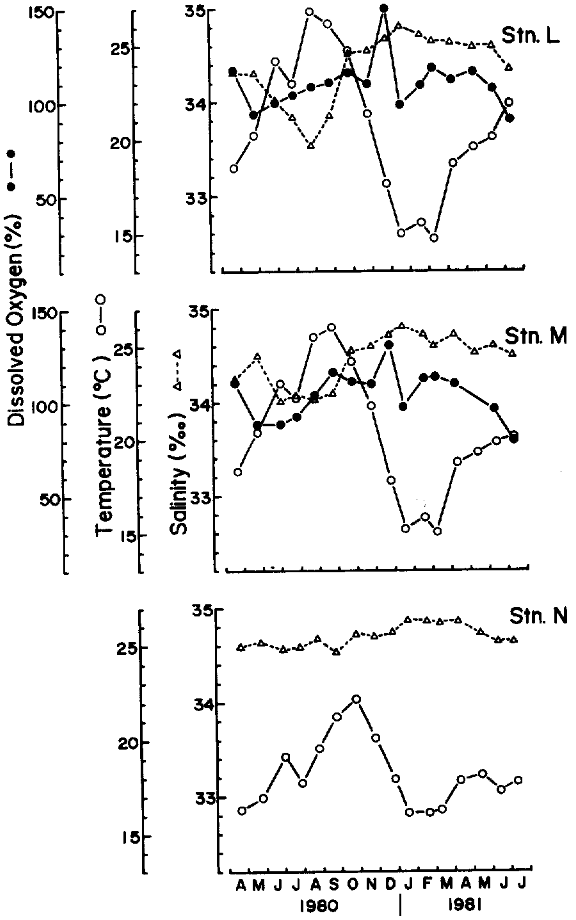

Fig. 13 Seasonal changes in temperature, dissolved oxygen and salinily in bottom water in Tosa Bay from April 22, 1980 to July 8, 1981. Dissolved oxygen at Stn. N was not measured.

33.5 to 35‰ throughout all surveys at all stations. Dissolved oxygen was 91-150% in saturation at Stn. L, and 79-130% at Stn. M. Dissolved oxygen at Stn. N was not measured. It was, however, suggested that oxygen deficiency took place only very weakly also at Stn. N if any because bottom sediments collected at this station were grayish brown in color and a sulfide odor was not noted at all. In summary, bottom water environments in this area was characterized by relatively stable and high temperature, salinity and dissolved oxygen concentration.

Table 11 shows the bottom sediment characters at these three stations. At Stns. L and M, mud content and organic matter content were very low. The bottom was occupied by sand. At Stn. N, mud content and organic matter content were a little

Table 11 Physico-chemical characters of sediments collected at stations L, M, N in Tosa Bay from April 22, 1980 to July 28, 1981. Mean ± standard deviation.

Station	Total carbon (mg/g dry mud)	Total nitrogen (mg/g dry mud)	Ignition loss (%)	Mud content (%)
L	1.85±0.69	0.23±0.08	3.5±0.4	9.8± 7.8
M	3.54±1.60	0.34±0.11	—	21.5±14.9
N	7.33±0.73	0.50±0.06	—	58.8± 4.3

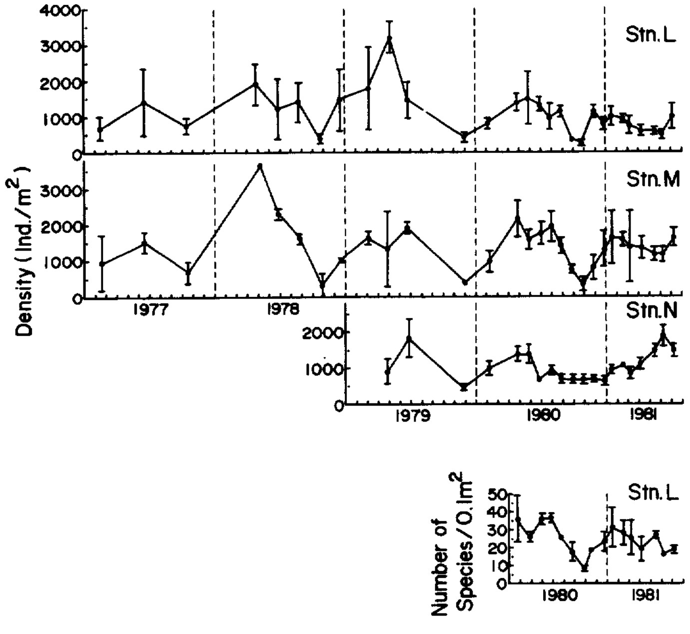

Fig. 14 Seasonal changes in density and species number of macrobenthic animals in Tosa Bay. Surveys were not carried out before April 26, 1979 at Stn. N. Identification was performed after April 22, 1980 only at Stn. L. Closed circle shows mean value and vertical bar shows standard deviation.

higher than at Stns. L and M. The bottom sediment at Stn. N consisted of muddy sand.

Benthic community: The mean density and number of species are shown in Table 12, their seasonal changes shown in Fig. 14, and seasonal changes in main component species shown in Fig. 15. Identifications of benthic animals were performed only at Stn. L after April 22, 1980.

Table 12 Means of density and number of species of the macrobenthic animals in Tosa Bay.

A) Density (February 16–17, 1977–July 8, 1981)

Taxonomic group	Stn. L		Stn. M		Stn. N	
	Ind./m²	%	Ind./m²	%	Ind./m²	%
Polychaeta	395	37.2	661	48.2	582	56.5
Crustacea	295	27.8	457	33.4	191	18.5
Echinodermata	7	0.6	27	2.0	33	3.2
Mollusca	314	29.6	152	11.1	30	2.9
Others	51	4.8	72	5.3	194	18.9
Total	1062		1369		1030	

B) Number of species (April 22, 1980–July 8, 1981)

Taxonomic group	Stn. L	
	No./0.1m²	%
Polychaeta	8.7	35.2
Crustacea	8.2	33.5
Echinodermata	0.4	1.8
Mollusca	5.9	24.2
Others	1.3	5.3
Total	24.5	

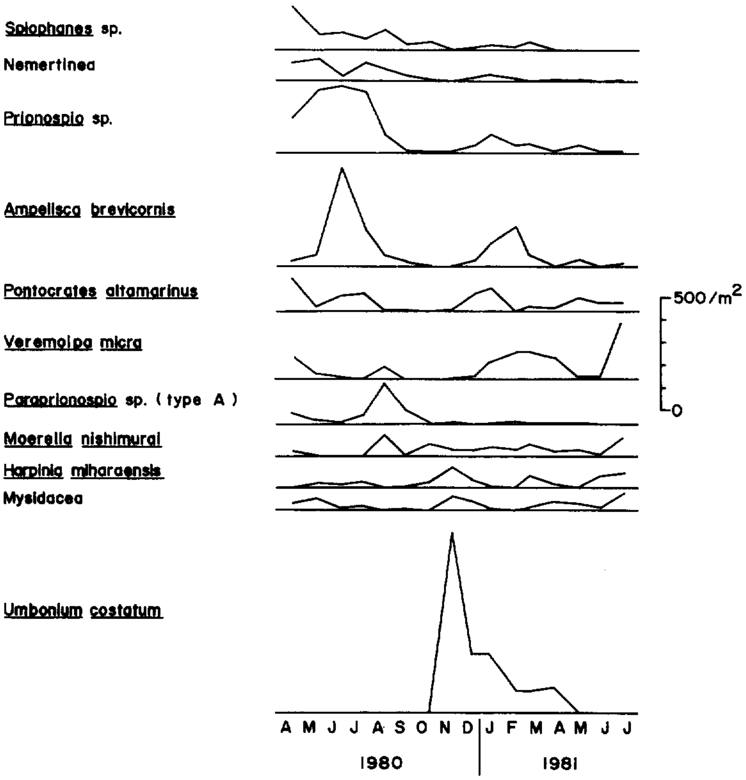

Fig. 15 Seasonal changes in density of numerically abundant species at Stn. L in Tosa Bay from April 22, 1980 to July 8, 1981.

At Stn. L, mean density of the benthic animals was fairly high, and polychaete, crustacean and mollusc were numerically abundant groups. Mean number of species was 24.5 per 0.1m^2. The density and number of species of benthic animals changed seasonally. They were high from spring and low in fall. Snail *Umbonium costatum*, polychaete *Prionospio* sp. and crustacean *Ampelisca brevicornis* were numerically abundant species. *Umbonium costatum* was collected from late November to early April. The other species did not show the apparent periodical seasonal changes.

Mean density of the benthic animals at Stn. M was the highest of these three stations, and polychaete and crustacean were abundant. The seasonal change in density at this station is similar to that at Stn. L.

Mean density of the benthic animals at Stn. N is approximately equal to that at Stn. L. Percentage composition of polychaete in density was about 57% and that of crustacean was about 19%. Density of benthic animals was relatively high in spring and slightly low from fall to winter.

Benthic communities in this area are characterized by relatively high density of benthic animals, high percentage of crustaceans in density and probably a large number of species.

Eutrophic stages of surveyed area

Benthic communities are qualitatively and quantitatively influenced by the eutrophication. In general, three stages have been recognized with distance from sources of organic input, namely, abiotic, polluted and normal stage, and in many cases, hypertrophic stage has been also found between polluted and normal stage (REISH, 1955, 1973; KITAMORI, 1966, 1970; PEARSON and ROSENBERG, 1976, 1978; DAUER and CONNER, 1980). But these four stages are not always arranged in order of abiotic, polluted, hypertrophic and normal from sources of organic input. KITAMORI (1970) illustrated the changes in abundance, number of species and ratio of abundance to number of species along a gradient of increasing organic matter. PEARSON and ROSENBERG (1978) showed the general outline of number of species, abundance and biomass along a gradient of organic enrichment, The outline was named SAB diagram by the capital letters of species, abundance and biomass. According to their studies, in abiotic stage, organic pollution is very severe and there are no macrobenthic animals. Polluted stage is largely influenced by organic pollution and is characterized by low biomass, low density, low species number and low species diversity, or by flourishes of a few very tolerant species. In hypertrophic stage, biomass, density, number of species and species diversity are all high. In normal stage, biomass, density and number of species are usually a little lower than in hypertrophic stage. Species diversity in this stage is approximately as high as that in hypertrophic stage.

Table 13 gives the outline of bottom environments and benthic communities of the surveyed areas—Osaka Bay, Hiuchi-nada and Tosa Bay. Judging from the benthic communities and bottom environments, eutrophic stage of each surveyed stations or areas is thought to be as follows;

Table 13 Bottom environments and benthic communities in Osaka Bay, Hiuchi-nada and Tosa Bay

	Osaka Bay					Hiuchi-nada		Tosa Bay		
	Stn. 1	Stn. 2	Stn. 3	Stn. 4	Stn. 5	15m>	15m≦	Stn. L	Stn. M	Stn. N
Depth (m)	10	15	20	28	39	15>	15≦	15	25	80
Bottom water										
Temperature (°C)	7.3–24.8	7.5–24.5	7.6–24.5	8.4–24.5	8.6–24.3	8.1–25.9*1	8.9–24.9*1	14.7–26.9	14.9–26.0	16.1–22.2
Salinity (‰)	31.25–33.04	31.70–33.31	31.88–33.44	31.97–33.46	32.07–33.87	32.21–32.45	32.27–32.90	33.56–34.80	33.99–34.82	34.54–34.88
Dissolved oxygen (%)	38–114	31–97	43–97	63–100	67–98	53–117	20–124	91–150	79–130	—
Sediments										
Total carbon (mg/g dry mud)	2.77	21.17	22.65	17.34	18.58	9.18	16.91	1.85	3.54	7.33
Total nitrogen (mg/g dry mud)	0.30	2.23	2.17	1.48	0.99	0.63	1.80	0.23	0.34	0.50
Ignition loss (%)	2.7	11.3	11.2	8.8	7.6	—	—	3.5	—	—
Mud content (%)	10.9	98.8	98.8	75.5	47.3	31.9	78.9	9.8	21.5	58.8
Benthic community										
Biomass (g/m²)	53.3	9.2	3.3	8.2	9.0	61.4	7.1	7.7	19.2	14.0
Density (ind./m²)	6349	401	87	269	282	2540	258	1062	1369	1030
No. of species/0.1m²	28.8	9.0	5.5	12.0	13.2	25.8	7.0	24.5	—	—
Composition in density (%)										
Polychaeta	90.7	89.1	61.4	53.0	59.7	52.7	54.8	37.2	48.2	56.5
Mollusca	3.4	5.2	11.1	32.1	11.2	7.5	35.5	29.6	11.1	2.9
Crustacea	1.7	2.4	12.6	3.6	6.5	31.7	2.5	27.8	33.4	18.5
Diversity (H')*2	2.73	2.41	2.26	3.05	3.27	3.04	2.01	3.68	—	—

Range or mean was shown.

*1 Mud temperature.

*2 $H' = -\sum_{i=1}^{s} \frac{n_i}{N} \log_2 \frac{n_i}{N}$ Where n_i is the number of individuals of the i-th species, N is the total number of individuals, and s is the total number of species.

abiotic stage...no stations

polluted stage...Stns. 2, 3 (Osaka Bay), deeper than 15m (Hiuchi-nada)

hypertrophic stage...Stn. 1 (Osaka Bay), shallower than 15m (Hiuchi-nada)

normal stage...Stns. 4, 5 (Osaka Bay), Stns. L, M, N (Tosa Bay)

Stns. 2, 3 in Osaka Bay and the area deeper than 15m in Hiuchi-nada are undoubtedly assigned to polluted stage. In these areas, number of the species and species diversity were both low, oxygen deficiency occurred strongly, organic matter content in sediment was high. Stn. 1 in Osaka Bay and the area shallower than 15m in Hiuchi-nada are thought to be hypertrophic stage. Organic matter content in sediment was low but dissolved oxygen in bottom water fell to about 40-50% in saturation. The biomass and density of benthic animals were very high and the species number was high. The low oxygen content, high biomass and high density show the presence of the influx of a large amount of organic matter into its water mass. Such organic matter is mainly derived from organic-rich fresh water and supports high biomass and high density of benthic animals. Stn. L in Tosa Bay is apparently normal stage. Dissolved oxygen deficiency of bottom water did not happen and the organic matter content in sediment was low. The number of species and species diversity were high, the density of macrobenthic animals was fairly high and the biomass was low. It seems to be suitable that Stns. 4, 5 in Osaka Bay are also treated as normal stage in spite of rather low density and species number of benhtic animals. In these stations, the fall in dissolved oxygen concentration was small, organic matter content in sediment was not so high, species diversiry was fairly high. Stns. L, M in Tosa Bay are lacking in some environmental and macrobenthic data. However, they are thought to be normal stage because there was no sign of eutrophication in water and bottom environments, and in the surveys in November, 1975 and June, 1976 the number of species and species diversity were both fairly high (number of species 13-27 per m^2, species diversity H' 3.17-4.20).

IV-3 Some biological data of the four types of *Paraprionospio*

Relation between body width and some other factors

Log body width is directly related to log wet weight as shown in Fig. 16 and body width is also directly related to total length as shown in Fig. 17. Setigers tend to approach constant number gradually with increasing body width (Fig. 18). Therefore, the total weight, total length and number of setigers can be estimated from the body

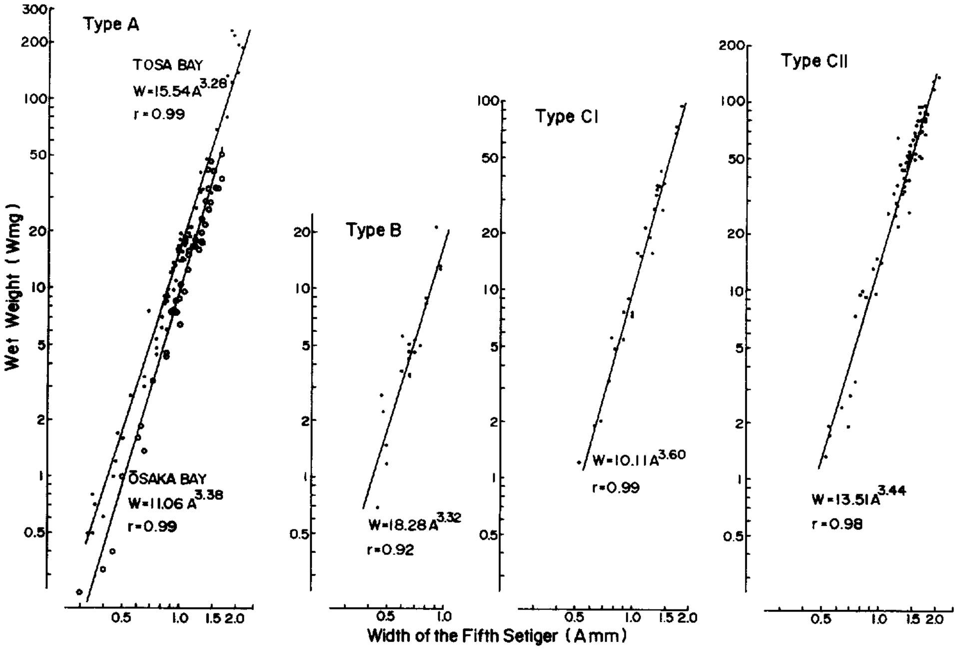

Fig. 16 Log width-log wet weight relationship of *Paraprionospio*. r shows correlation coefficient.

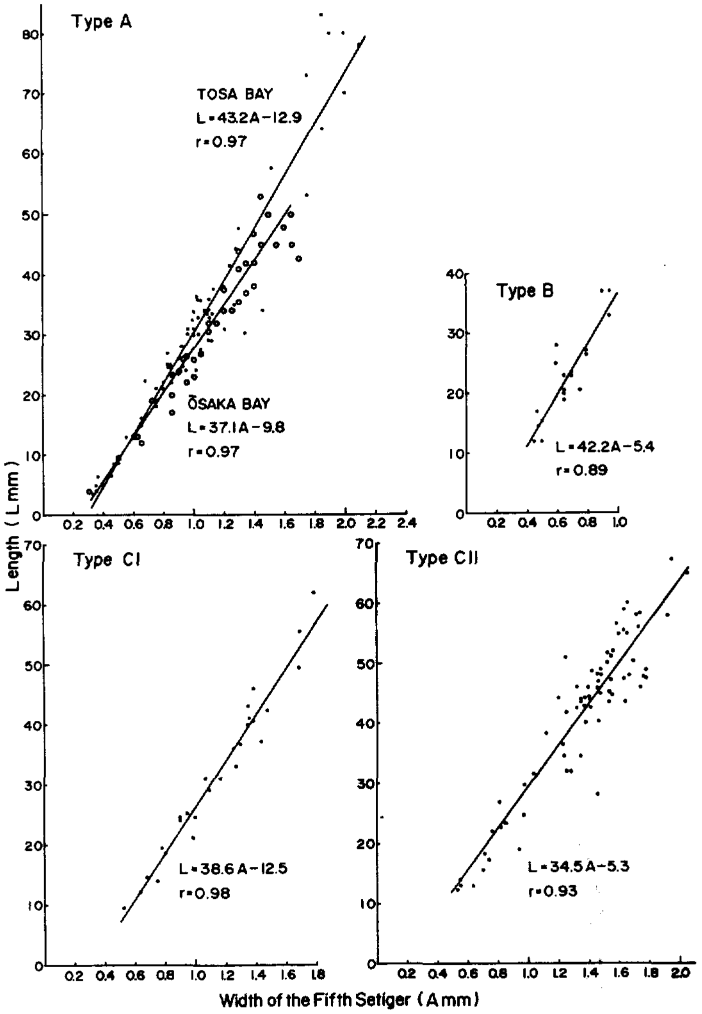

Fig. 17 Width-length rlelationship of *Paraprionospio*. r shows correlation coefficient.

width, even if the worm is damaged.

Eggs and sperm

The eggs of all four types fixed in formalin solution are light orange in color and nearly spherical in shape but sometimes distorted or flat. Type CII has the largest egg diameter of all four types. Mature egg diameter of type CII is 120-220μm, and that of the other three types is about 100-170μm. Number of the eggs per female is directly related to body weight (Fig. 19). Egg number per female of type A is about twice as many as that of types CI and CII in the case of the same body weight. For example, a type A female of 100mg in body weight produces about 41,000 eggs and the type CI and CII of the same weight produce about 21,000 eggs. Maximum egg number of type A measured is more than 100,000, and that of type CI and CII is about 26,000-

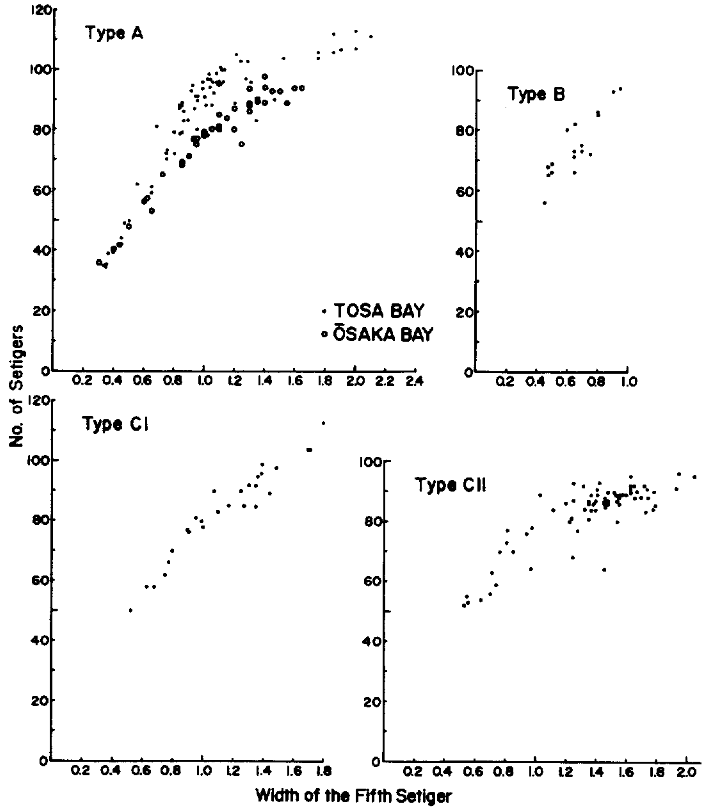

Fig. 18 Width-number of setigers relationship of *Paraprionospio*.

28,000. The exact egg number of type B is unknown because no complete females with eggs were obtained. But the maximum number is roughly estimated about 10,000 from the egg diameter and the maximum body weight. Type A has a pelagic larval stage (YOKOYAMA, 1981), and judging from the egg diameter and the egg number produced by a female (THORSON, 1950; HERMANS, 1979), types B, CI, CII are also probably thought to undergo pelagic development.

The sperm morphology of the four types resembles each other very well. It is difficult to distinguish them under the light microscope. Fig. 20, for instance, shows the sperm morphology of type A. The sperm is composed of a nearly spherical head, a small middle piece and a long tail.

Eggs and sperm of all four types are observed first from setiger 14-21 and are observed to the almost rear end. The male and female resemble each other very well in external morphology. So, adult worms which have lost their setigers containing eggs or sperm, or young worms not containing eggs or sperm can not be sexed.

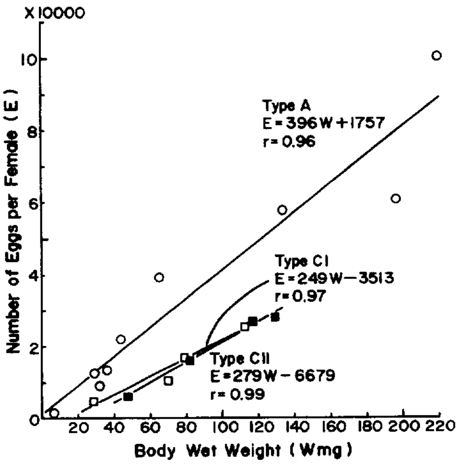

Fig. 19 Body wet weight-number of eggs per female relationship of *Paraprionospio*. r shows correlation coefficient.

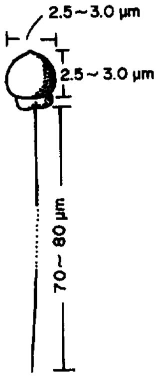

Fig. 20 Sperm of *Paraprionospio* sp. (type A).

IV-4 Life history

Type A

Osaka Bay: As mentioned in chapter III, type A was distributed at the depths shallower than 20m in Osaka Bay. In 1979-1980 surveys, a large number of type A were collected at Stns. 1 and 2 shallower than 15m in depth, whereas hardly collected at Stns. 3-5 deeper than 20m in depth (Fig. 21). Annual mean density of this type at Stn. 1 (10m in depth) reached 1641 individuals per m², and at Stn. 2 (15m in depth) showed 174 individuals per m².

The seasonal changes in density of type A at Stn. 1 was entirely different from that Stn. 2 (Fig. 22). At Stn. 1, the density was fairly stable at the level of about 250 individuals per m² from April to early July, then increased rapidly from late July to August, and reached about 6000 individuals per m² from September to October. Such a rapid increase in density was due to the recruitment of very many juveniles. Rapid decrease took place after November. The density from December to March fell to about 50 individuals per m². At Stn. 2, the density of type A exceeded 1000 individuals per m² in

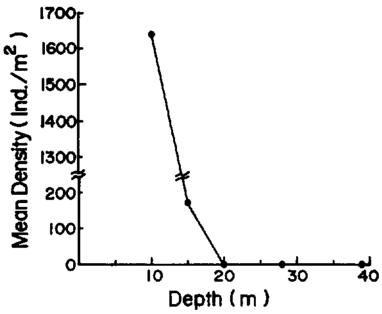

Fig. 21 Relation between water depth and annual mean density of *Paraprionospio* sp. (type A) in Osaka Bay from April 18, 1979 to March 9, 1980.

spring, but diminished from June to July, and this type was absent or extremely rare after August. Seasonal changes in the percentage composition of type A in density at each station were similar well to that in the density (Fig. 23).

Fig. 24 shows body width-frequency histograms at Stn. 1. It is easy to follow peaks through from month to month. Recruitment of benthic juveniles occurred from late July to early September. Some of these juveniles were about 4mm in total length and had about 40 setigers, which are thought to be the specimens immediately after the settlement (YOKOYAMA, 1981). The growth took place rapidly from September to October. The maximum growth rate was estimated at 11.4mg and 19.8mm per month from the mean body width on September 2 and September 16, 1979. The growth was slow in cold months. It began again from April. Specimens with eggs or sperm were observed from middle of May to early September. Judging from the seasonal change in egg diameter (Fig. 25A) and the appearance of the specimens with gametes, spawning season is considered to begin in mid-June and to continue for about two months. Pelagic stage of the larva is considered to be about a month because the settlement occurred about a month after the beginning of spawning. The longevity is about a year. Some part of the juveniles already contained large eggs more than 100μm in diameter or ripe sperm from August to September (Figs. 24, 25B),

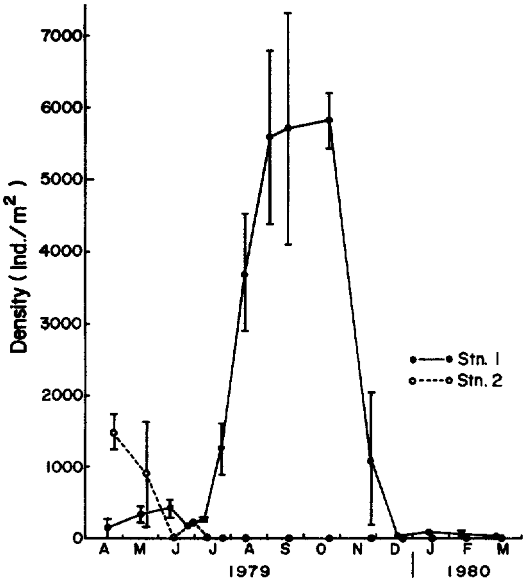

Fig. 22 Seasonal changes in density of *Paraprionospio* sp. (type A) in Osaka Bay from April 18, 1979 to March 9, 1980. Closed and open circles show mean value and vertical bar shows standard deviation.

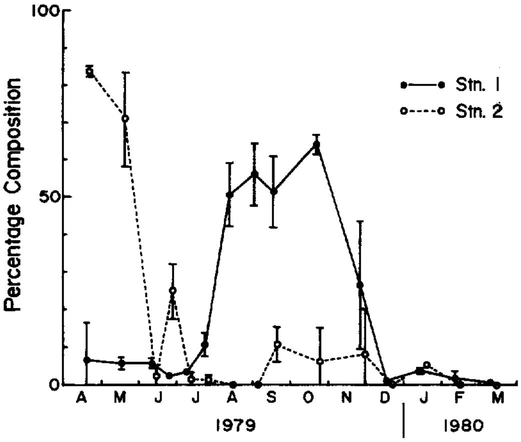

Fig. 23 Seasonal changes in percentage composition of *Paraprionospio* sp. (type A) in density in Osaka Bay from April 18, 1979 to March 9, 1980. Closed and open circles show mean value and vertical bar shows standard devitation.

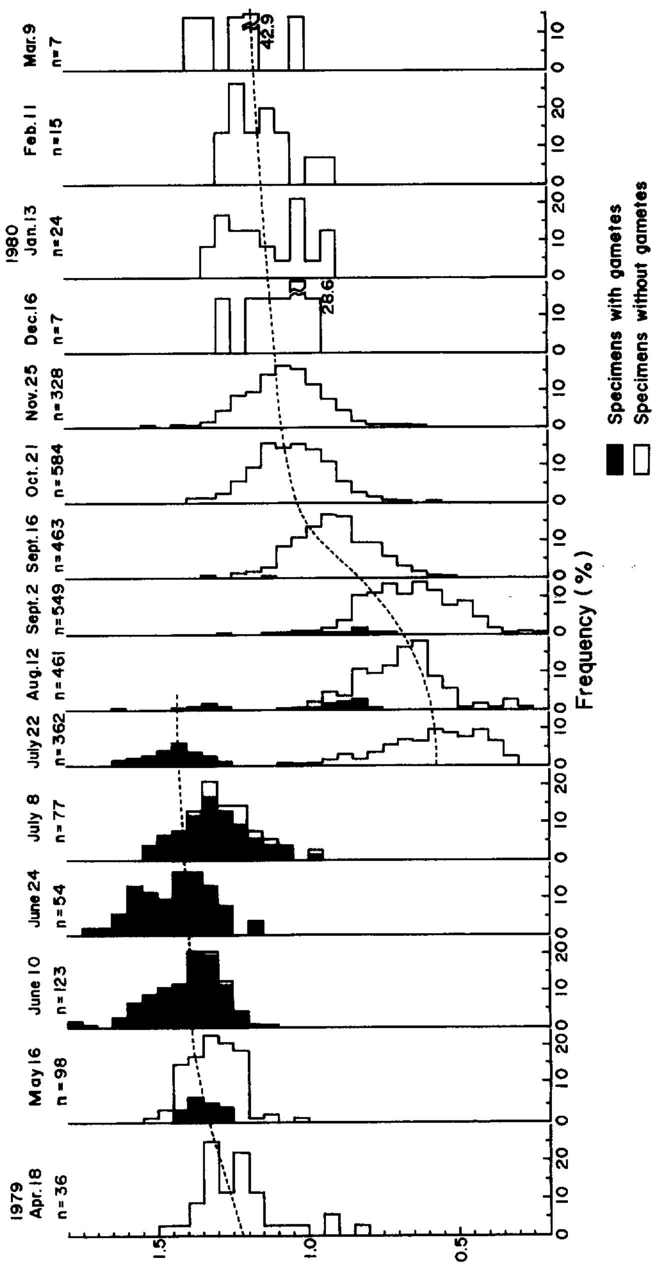

Fig. 24 Seasonal changes in body width frequency of *Paraprionospio* sp. (type A) at Stn. 1 in Osaka Bay from April 18, 1979 to March 9, 1980. n shows the number of measured specimens. A dotted line was drawn from mean body width of each size group.

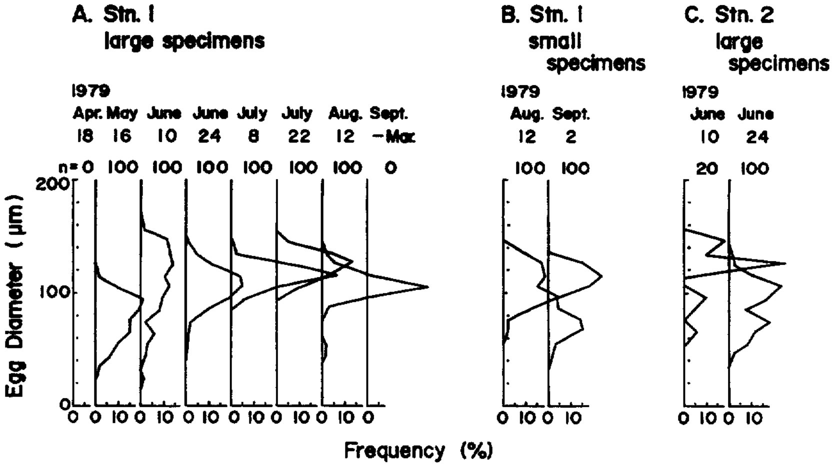

Fig. 25 Seasonal changes in egg diameter of *Paraprionospio* sp. (type A) at Stns. 1 and 2 in Osaka Bay. Large specimens are larger than 1mm in body width and small specimens are smaller than 1mm in body width. n shows the number of measured eggs.

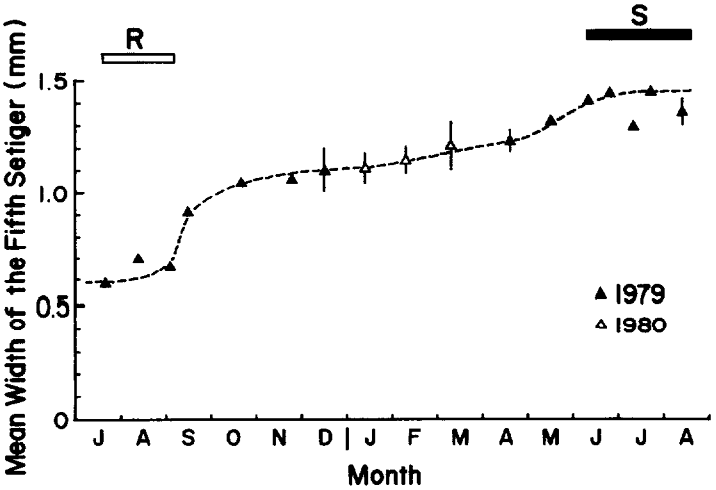

Fig. 26 Growth curve of *Paraprionospio* sp. (type A) at Stn. 1 in Osaka Bay. Vertical bar shows 95% confidence limits. R: recruitment period. S: spawning period.

which displays the ability of the rapid sexual maturity of type A. However, the new recruitment due to the spawning of these small precocious worms was not observed, probably because the density of such worms was low and they have only a small number of eggs per female. The smallest specimen containing gametes was 0.75mm in width, 20mm in length and 6mg in weight. These results are summarized in Fig. 26.

At Stn. 2, the growth from spring to summer was very ill and the percentage of the specimens with gametes was low (Fig. 27). But since large eggs more than 100μm in diameter were observed (Fig. 25C), the spawning seems to occur.

It is clear from the described facts that Stn. 1 is the suitable habitat for type A, where this type can maintain the stable life cycle. At Stn. 2, the recruitment of type A in 1978 was successful, which is deduced from high population density in the spring of 1979, however, the recruitment in 1979 was very poor. This shows that Stn. 2 is not always the suitable habitat for type A.

Tosa Bay: In Tosa Bay, type A was abundant at the depth of 15m (Stn. L) and the mean density in 1977-1981 was 82.4 individuals per m^2 (Table 4). The seasonal change in the density of type A at Stn. L was not necessarily similar from year to year, but relatively high density (200-500 individuals per m^2) was usually observed in summer months. The percentage composition indistinctly showed somewhat high value (15-30%) from June to December.

Fig. 28 shows the growth curve. There are two recruitment periods, one is the early summer months (May to July) and the other is the fall months (October to November). The major recruitment period is probably the former. The life history of early summer recruitment group is similar to that at Stn. 1 in Osaka Bay. The growth was fast from July to October. It almost stopped in winter and began again in spring. The spawning season was from April to July. In this period, the females have the many large eggs more than 100μm in diameter. The longevity is about a year. The fall recruitment juveniles are derived from the spawning of some precocious individuals settled in early summer months. They grew rapidly and this recruitment group and early summer recruitment group united to form one group in spring.

According to some ecological observations, this type lives in the fragile tube made of a mucoid secretion, and stretches the palpi, branchiae and anterior end of the body out of the tube for feeding and respiration. Type A seems to feed on the suspended and deposited organic particles.

The life history in Tosa Bay is different from that in Osaka Bay to some extent, however, the breeding is roughly restricted to warm season in both areas.

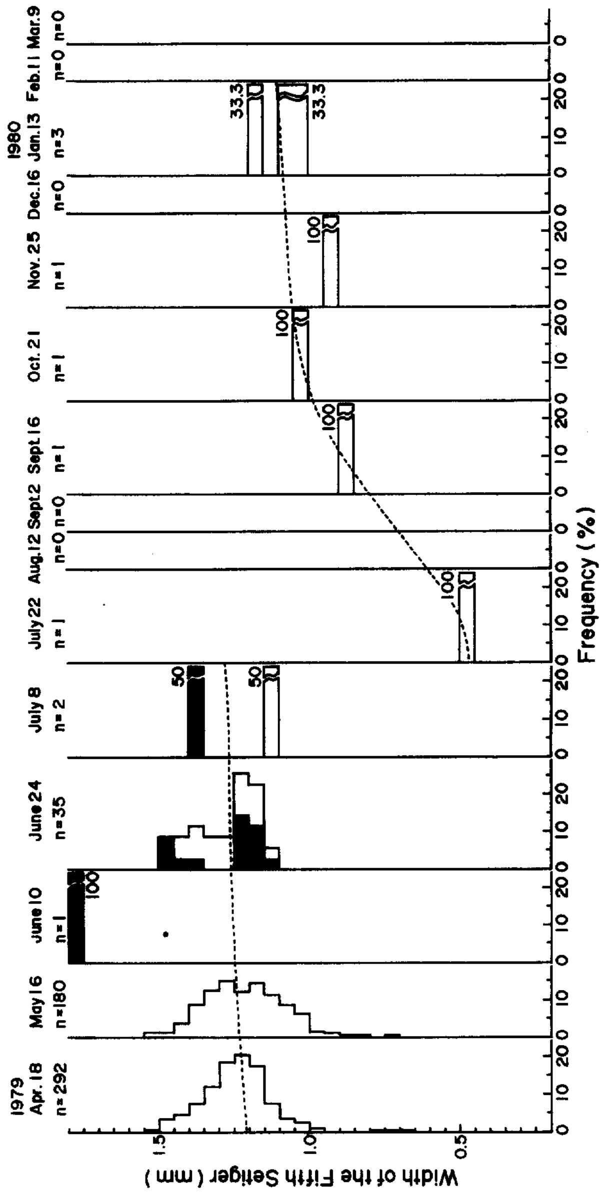

Fig. 27 Seasonal changes in body width frequency of *Paraprionospio* sp. (type A) at Stn. 2 in Osaka Bay from April 18, 1979 to March 9, 1980. See Fig. 24.

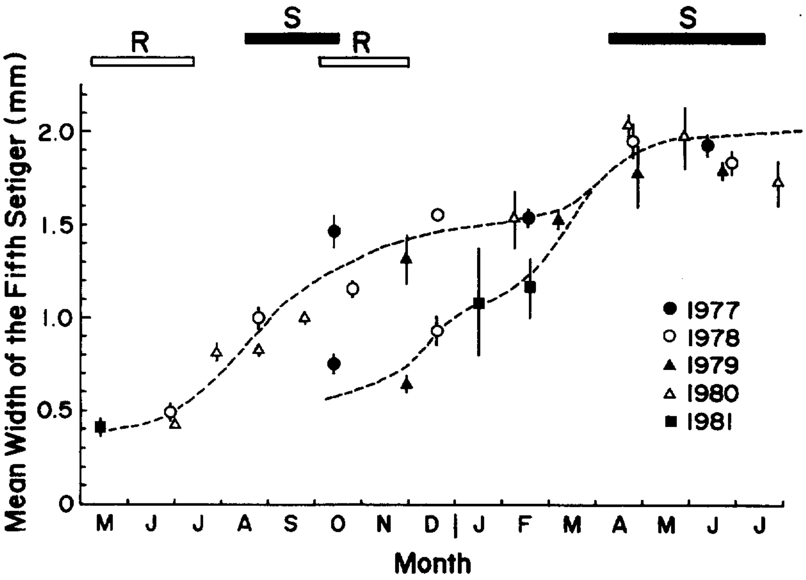

Fig. 28 Growth curve of *Paraprionospio* sp. (type A) at Stn. L in Tosa Bay. See Fig. 26.

Type B

Type B was collected in Hiuchi-nada and at Stns. 2-5 in Osaka Bay. In Hiuchi-nada, mean density per m² was 10.9 (shallower than 15m in depth) and 23.9 (deeper than 15m in depth), mean percentage composition was 1.1 (shallower region) and 9.0 (deeper region). In Osaka Bay, mean density per m² was 0 (Stn. 1), 12.7 (Stn. 2), 12.3 (Stn. 3), 4.0 (Stn. 4) and 7.7 (Stn. 5), and mean percentage composition was 0 (Stn. 1), 6.6

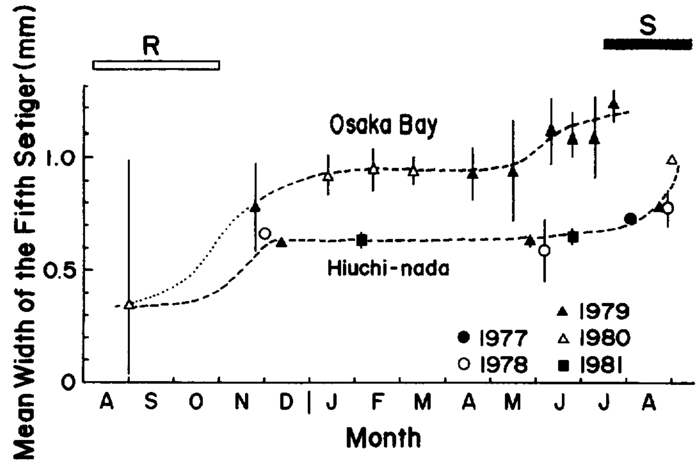

Fig. 29 Growth curve of *Paraprionospio* sp. (type B) at Stns. 2 and 3 in Osaka Bay and the area deeper than 15m in depth in Hiuchi-nada. See Fig. 26.

(Stn. 2), 11.7 (Stn. 3), 2.2 (Stn. 4) and 2.1 (Stn. 5). The life history of type B was examined at the bottom deeper than 15m in Hiuchi-nada and Stns. 2 and 3 in Osaka Bay, where the density and the percentage composition were both relatively high. These stations are probably the suitable habitat of type B.

Fig. 29 shows the growth curve. The recruitment seems to take place from late summer to fall. But, only small number of the juveniles was collected during this period, probably because of the use of 1mm mesh sieve for collection except the case of Hiuchi-nada after December, 1979. 1mm mesh is too large for collecting the juvenile individuals effectively. Growth occurred from fall to January and in summer. It stopped from February to spring. In summer body width reached 0.8mm in Hiuchi-nada and 1.1mm in Osaka Bay. The individuals with gametes were collected in summer, namely, only in August in Hiuchi-nada and from early June to early September in Osaka Bay. Mean egg diameter was smaller than 100μm till early July and then exceeded 100μm for about two months. So, it is supposed that the spawning took place from July to September. The longevity is about a year.

Type CI

The distribution depth range of type CI in Tosa Bay was 15-110m. Mean density and mean percentage composition in this area from 1977 to 1981 were both extremely low, 2.1 individuals per m^2 and below 1% respectively. The density, percentage composition and body width did not show the apparent seasonal fluctuation at all. For these reasons, the life history of type CI could not be clarified.

Type CII

Type CII inhabited at the depths 25-98m in Tosa Bay and was collected frequently on muddy sand bottom deeper than 35m, so the specimens collected at the stations of 35-70m water depth and Stn. N (80m in depth) were used for the life history study of this type.

Fig. 30 shows the growth curve. The benthic juveniles were recruited from October to winter and grew from winter to spring. They seem to be matured and spawn from June to October, when the eggs were fairly large, 130-180μm in mean diameter. The longevity is about a year.

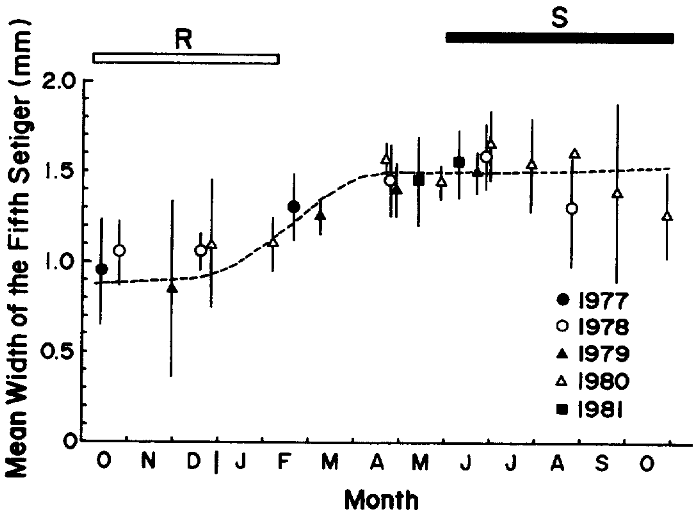

Fig. 30 Growth curve of *Paraprionospio* sp. (type CII) at a depth of 35–80m in Tosa Bay. See Fig. 26.

V Four types of *Paraprionospio* as environmental indicators

Single species or species group is frequently used to indicate some environmental conditions (Kitamori, 1963; Bagge, 1969; Pearson, 1971, 1975; Leppäkoski, 1975; Rosenberg, 1976 etc.). For example, *Capitella capitata*, *Scolelepis fuliginosa*, *Streblospio benedicti*, *Polydora ligni*, *P. ciliata*, *Hydrobia ulvae* and so on are known to be species associated with organic pollution (Pearson and Rosenberg, 1978). The reasons why some indicator species can live and flourish under some environmental conditions are also important subjects to be investigated. In this chapter, utility of the four types of *Paraprionospio* as environmental indicators and the reasons for their prosperity will be discussed. For this purpose, the biological and ecological knowledge of the objective species and the information about the macrobenthic community and environmental conditions are needed. They were given in chapter III-IV.

Type A

As shown in chapter III, type A is a coastal waters species to live mainly shallower than 20m in depth. Coastal waters frequently undergo organic pollution by the organic-rich fresh water inflow. If there is some relation between eutrophic stage and type A, we can use this type as its indicator. Therefore, the relations between eutrophic stages and the three factors of type A (density, percentage composition in density, rank in density) were examined (Table 14). These factors were somewhat high at Stn. L in Tosa Bay (normal zone), and very high at Stn. 1 in Osaka Bay (hypertrophic zone)

Table 14 Relation between *Paraprionospio* sp. (type A) and eutrophic stage. Each value was calculated from all surveys dealt in chapter IV. Only rank in Tosa Bay was determined from the surveys from April 22, 1980 to July 8, 1981.

Eutrophic Stage	Area	Station	Depth (m)	Type A				
				Ind./m² Mean	(Range)	Percentage composition Mean	(Range)	Rank in density
Normal	Tosa Bay	L	15	82.4	(0–473)	6.8	(0–28.0)	11
		M	25	0.3	(0–2)	0.1	(0–0.3)	20<
		N	80	0	(0–0)	0	(0–0)	
	Osaka Bay	4	28	0	(0–0)	0	(0–0)	
		5	39	0	(0–0)	0	(0–0)	
Hypertrophic	Osaka Bay	1	10	1641.3	(23–5807)	19.4	(1.0–64.2)	1
	Hiuchi-nada		15>	0	(0–0)	0	(0–0)	
Polluted	Osaka Bay	2	15	173.7	(0–1475)	14.4	(0–83.7)	1
		3	20	0.3	(0–5)	0.2	(0–2.6)	20<
	Hiuchi-nada		15≦	0	(0–0)	0	(0–0)	

and Stn. 2 in Osaka Bay (polluted zone). Especially at hypertrophic and polluted zones, type A was the most dominant species and sometimes reached very high density (1500-6000 individuals per m²) and very high percentage composition (65-85%). Also at Stn. L in Tosa Bay, type A sometimes showed 200-500 individuals per m² in density, and 15-30% in percentage composition. But these values are fairly low as compared with those at Stns. 1, 2 in Osaka Bay, and the rank in density is the eleventh. Type A in Tosa Bay is merely one of the constituents of the community (Figs. 15, 31c). After all, it is concluded that the dominant and numerous appearance of type A suggests eutrophication. However, type A is not always dominant even at hypertrophic or polluted zone as observed in Hiuchi-nada and at Stn. 3 in Osaka Bay.

Why can type A sometimes prosper very well at hypertrophic or polluted zone? In the case of the hypertrophic zone, namely, Stn. 1 in Osaka Bay, the reason is probably that the ecological and physiological features of type A are suitable to live in eutrophic areas. Type A is characterized by the summer recruitment, rapid growth and fairly high tolerance to physico-chemical environmental factors such as low oxygen concentration, low oxidation-reduction potentials, high H_2S. The settlement period of type A (late July-early September) coincided with the rapid decrease period in the density of the other benthic animals (Fig. 31A). Surplus habitat and food are probably produced by this decrease, and just then the juveniles of type A are settled, use these sufficient surplus and grow rapidly. It seems probable that the decrease in density of the benthic animals except type A is due to the loss of the species which can not tolerate low oxygen concentration, because the decrease in density occurred with the

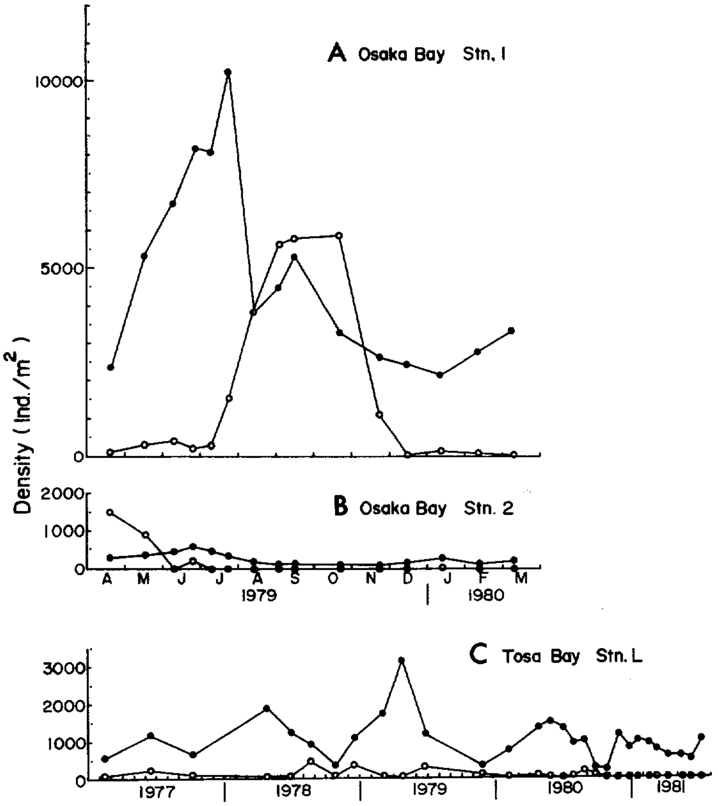

Fig. 31 Seasonal changes in density of *Paraprionospio* sp. (type A) (○) and density of total benthic animals except type A (●) in Osaka Bay and Tosa Bay.

summer oxygen deficiency of bottom water. Polychaetes *Euchone* sp., *Pseudopolydora* sp., crustacean *Corophium acherusicum*, echinoderm *Ophiophragmus japonicus*, molluscs *Musculus senhausia*, *Raete rostralis*, *Theora lubrica* decreased rapidly in this period (Fig. 11, Appendix table 1). However, type A can be recruited and survive under low oxygen conditions. Probably for above mentioned reasons, type A can prosper in hypertrophic zone. That is to say, the prosperity of type A is thought to be caused by eutrophication. This supports that the use of type A as an eutrophic indicator is reasonable.

The prosperity of type A at Stn. 2 in Osaka Bay (polluted zone) seems to be mainly dependent on the tolerable ability of type A to the physico-chemical environment. At this station, the period when type A settles is not so important because the sediment in this station has a large amount of organic matter which is used for food and because density of the benthic animals except type A is fairly low throughout the year (Fig 31B). Therefore, whenever type A settles, this type will find sufficient food and habitat.

Type A is mainly distributed in coastal waters shallower than 20m in depth, and the areas where the density, percentage composition and rank in density of type A are high are hypertrophic or polluted zone. Thus, type A can be utilized for the eutrophic indicator on coastal waters.

Type B

Type B is an inland sea mud and muddy sand bottom species. A little deeper mud bottom in inland sea is thought to be an area where the organic matter is resedimented. Type B is mainly distributed in such areas. Therefore, there is a possibility that this type can be also used as an eutrophic indicator like type A. The relations between eutrophic stages and the three factors of type B (density, percentage composition in density, rank in density) were shown in Table 15. Since type B lives in every zone, the presence of this type itself does not serve as an indicator of eutrophication. But the density, percentage composition and rank are all higher in polluted zone than in normal and hypertrophic zone. Thus, the eutrophic stage may be estimated by these values. The percentage composition shows eutrophic stage more distinctly than the density, because in polluted zone the increase in density of type B and the decrease in total density of benthic animals usually occurs simultaneously, and consequently the relative rate of type B becomes high. The percentage composition is more suitable for eutrophic indicator than the density.

Table 15 Relation between *Paraprionospio* sp. (type B) and eutrophic stage. Each value was calculated from all surveys dealt in chapter IV.

Eutrophic stage	Area	Station	Depth (m)	Type B Ind./m² Mean	(Range)	Percentage composition Mean	(Range)	Rank in density
Normal	Tosa Bay	L	15	0	(0–0)	0	(0–0)	
		M	25	0	(0–0)	0	(0–0)	
		N	80	0	(0–0)	0	(0–0)	
	Osaka Bay	4	28	4.0	(0–15)	2.2	(0–8.3)	16
		5	39	7.7	(0–50)	2.1	(0–7.7)	9
Hypertrophic	Osaka Bay	1	10	0	(0–0)	0	(0–0)	
	Hiuchi-nada		15>	10.9	(0–43.3)	1.1	(0–4.0)	20<
Polluted	Osaka Bay	2	15	12.7	(0–60)	6.6	(0–20.0)	6
		3	20	12.3	(0–50)	11.7	(0–30.0)	1
	Hiuchi-nada		15≦	23.9	(0.6–83.6)	9.0	(0.3–37.2)	2

Type B mainly inhabits the area where the organic matter in sediment is rich and the density of benthic animals is low or moderate throughout the year. This type seems to feed on deposited or near bottom suspended particles (TAGHON et al., 1980; DAUER et al., 1981). Consequently, whenever type B settles, this type will be able to find the foods and habitat sufficiently. Therefore, the period when this type is recruited is not so important. The prosperity of type B may be dependent on the fairly high tolerance to physico-chemical enviromental factors peculiar to eutrophic areas, such as low oxygen concentration, low oxidation-reduction potentials, high H_2S concentration. However, it is not clear why the density of type B does not become so high.

The density, percentage composition and rank of types A and B can be used for the eutrophic indicators. Type A prospers especially in coastal hypertrophic zone and type B prospers in a little deeper polluted zone. By using both types together, we will be able to estimate eutrophic areas more distinctly.

Type CI

Type CI was collected in a wide variety of habitats and the density is usually very low. The life history can not be clarified. For these reasons, the use of this type for an indicator organism is difficult.

Type CII

Type CII is an offshore waters species. It was collected on muddy sand bottom deeper than 35m in Tosa Bay and was not recorded in an inland sea region at all. Oceanographic conditions in offshore region are characterized by the small variation of water temperature and high and stable salinity. At the depth of 80m in Tosa Bay, which is the suitable habitat for type CII, the difference between minimum and maximum temperature was 6.1°C and salinity ranged from 34.54 to 34.88‰. Type CII will be restricted to some extent by these oceanographic conditions.

Type CII will be able to be utilized for an offshore waters indicator organism and we can estimate the area influenced by offshore water using this type.

VI Discussion

The genus *Paraprionospio* now consists of the four species, *P. pinnata* (EHLERS, 1901), *P. africana* (AUGENER, 1918), *P. treadwelli* (HARTMAN, 1951) and *P. lamellibranchia* HARTMAN 1974 (YOKOYAMA and TAMAI, 1981). *P. pinnata* is a cosmopolitan species (FOSTER, 1969, 1971; BLAKE and KUDENOV, 1978; LIGHT, 1978). *P. africana* was reported from off western Africa (AUGENER, 1918; MONRO, 1930). *P. treadwelli* was recorded from off eastern U. S. A. (HARTMAN, 1951) and *P. lamellibranchia* was recorded from the Mozambique Channel and the northern Indian Ocean (HARTMAN, 1974). The original morphological descriptions of these four species are, however, all insufficient and the characters used for discrimination among the present four types (A, B, CI and CII) are not almost treated in previous studies (YOKOYAMA and TAMAI, 1981). Furthermore, even the description of *P. pinnata*, the most common *Paraprionospio* species, is taxonomically confused. For example, FOSTER (1969) stated that *P. pinnata* had or did not have the filament at the base of the third branchia, transverse dorsal crests and transparent dorsal cuticle. However, these must be the important characters to divide into species or subspecies. There is also the disagreement in the shape of branchial lamellae (YOKOYAMA and TAMAI, 1981). As shown in this paper, the present four types are distinguished not only by morphological characters but also by ecological items, such as habitat preference, maximum density attainable, adult size and number of the eggs per female. These facts suggest that each type can be treated as valid species. But, because of the insufficiency of the previous descriptions, the examinations of both the type specimens of each species and the specimens collected all over the world are needed for the identification of the present four types. For this reason, the species name could not be determined in this study.

According to this study and TAMAI (1981), YOKOYAMA and TAMAI (1981), the geographical distribution of each type of *Paraprionospio* in Japan is as follows: Type A occurs on the Pacific side from off Ibaragi prefecture southward to Tosa Bay, in Seto Inland Sea and on the Japan Sea side from Wakasa Bay to off Tottori prefecture. Type B occurs in Kii Channel, Seto Inland Sea, Wakasa Bay and Ariake Sea. Type CI occurs on the Pacific side from off Ibaragi prefecture southward to Kyushu, in Seto Inland Sea and Wakasa Bay. Type CII occurs in Tanabe Bay, Tosa Bay and Wakasa Bay. "*P. pinnata*" was also collected in further northern areas exceptionally, namely, Hakodate Bay in Hokkaido (NAKAO, 1982) and Nanao Bay in Ishikawa prefecture (MIYADI and MASUI, 1942b). But the distributional area of *Paraprionospio* in Japan is almost restricted northward to 37°N, which is approximate northern limit of the effects of the warm Kuroshio and Tsushima Currents.

There are two methods in order to estimate environmental conditions from benthic animals. One is the method using the characteristics which express the community structure and the other is the method using indicator organisms. KITAMORI (1975) and PEARSON and ROSENBERG (1976, 1978) have mentioned that the structural change in quantitatively sampled benthic communities is more useful and the indicator organisms only play a supplemental role. Certainly, the characteristics of community structure shown by biomass, density, number of the species, diversity and similarity are all good indicators. But, to calculate number of the species, diversity and similarity of benthic communities, we must identify all collected specimens. For this purpose, wide taxonomic knowledge and time-consuming procedure are needed. On the contrary, the indicator organisms associated with some environment enable us to recognize the environmental conditions intuitively and quickly, though the accuracy may not be so good. For example, as shown in this study, we can recognize degree of eutrophication of the region by use of types A and B. The appearance of type CII shows the influence of offshore water.

Both type A and type B are good indicator of eutrophic zone, but they are also sometimes collected in normal zone. Then recognition of eutrophic zone can be done by their density, percentage composition and dominance rank in density. Identification of these types is easy. In the case of type CII, the distribution is completely restricted to offshore waters and this type appears there frequently. The identification is not so difficult. These three types are practically useful as indicator organisms.

Generally, the utility as an indicator organism changes seasonally because the density usually shows seasonal fluctuation. The survey should be carried out in the period when the many specimens of indicator organisms can be collected, namely, the recruitment period and the little later. The suitable season for the survey is from summer to fall for type A and is from fall to winter for type B.

In inland sea region, polluted area and the degree of pollution could be roughly estimated also by the previous method using "*P. pinnata*" (KITAMORI, 1969; JOH et al., 1969, 1978a; SANUKIDA et al., 1979, 1981) because, in this region, "*P. pinnata*" is mainly composed of type A and type B, both of which are useful eutrophic indicator organisms. Type CI is also sometimes distributed in this region, but usually the density is very low, therefore, the distributional pattern of "*P. pinnata*" is scarcely influenced by the presence of this type. In offshore region, "*P. pinnata*" is composed of types A, CI and CII. Especially, deeper than 25m in depth, only types CI and CII are mainly distributed. These two types are independent of eutrophication and pollution.

In Japan, semelid small bivalve *Theora lubrica* is also used as an eutrophic indicator (KIKUCHI and TANAKA, 1976; SANUKIDA et al., 1979, 1981; IMABAYASHI, 1983). This species is widely distributed in the area of strong embayment degree (MIYADI et al., 1944b; HABE, 1956), and the density sometimes exceeds 1000 individuals per m^2 (KIKUCHI and TANAKA, 1976, 1978). The mode of seasonal change in population and settlement period of benthic juveniles considerably vary with locality (MUKAI, 1974; KIKUCHI and TANAKA, 1976; SANUKIDA et al., 1979, 1981). The species has short life span, rapid growth and small maturation size (KIKUCHI and TANAKA, 1976). The data in the present study show that *T. lubrica* and type B have similar distributional area. Both species were widely distributed on mud and muddy sand bottom in inland sea area. However type B tends to be abundant in mud bottom area where the oxygen deficiency happens rather strongly (e. g. Stns. 2 and 3 in Osaka Bay, deeper than 15m in Hiuchi-nada), while *T. lubrica* is usually abundant in the area where oxygen deficiency does not happen so strongly (e. g. Stns. 4 and 5 in Osaka Bay, shallower than 15m in Hiuchi-nada). KIKUCHI (1964) said that in brackish lagoon, Nakaumi, all benthos including bivalve molluscs *T. lubrica* and *Raeta pulchella* died out but only "*P. pinnata*" remained alive under severe dissolved oxygen deficiency in summer. SANUKIDA et al. (1984) also reported in eastern Hiuchi-nada that when dissolved oxygen fell below 2.0ppm in September, *T. lubrica* died completely but type B could survive.

Comparing the life history of type A in Osaka Bay with that in Tosa Bay, it is noticed that the reproductive period begins earlier and is longer in Tosa Bay. There are many factors affecting reproduction (SCHROEDER and HERMANS, 1975), but generally temperature is thought to be the most important one. At first, this difference of life history between these two areas was seemed to be due to the difference of water temperature. The reproductive period of type A is restricted roughly in warm season. In Tosa Bay, the minimum temperature is about 7°C higher than in Osaka Bay and duration higher than 20°C is about 50 days longer. As a result, the reproductive period will become earlier and longer in Tosa Bay. However, in Kumihama Bay, which is colder than Osaka Bay, pelagic larvae were mainly collected during the fairly long period of May to December, recruitment occurred from July to December and the specimens with gametes were observed throughout the year (YOKOYAMA, 1982). The life history of type A in Kumihama Bay is rather similar to that of Tosa Bay than Osaka Bay. This fact shows that the temperature is not the only factor affecting gametogenesis and spawning of this type. But at least it is certain that the annual life cycle is repeating regularly every year and that the settlement period is restricted to summer and fall seasons in all these three areas.

In order to inhabit polluted area, the organisms must undoubtedly have tolerable ability to physico-chemical environmental conditions peculiar to polluted area, such as low oxygen concentration and high H_2S concentration. Besides this ability, the opportunistic nature of pollution indicator species has also recently been brought under workers' notice (GRASSLE and GRASSLE, 1974; WARREN, 1976, 1977; KIKUCHI and TANAKA, 1976). Among several characteristics with opportunistic species, it is thought to be especially important that reproduction occurs asynchronously, and consequently the breeding season of population is extremely extensive, because the rapid colonization into unpredictably produced vacant habitat is largely due to this characteristics of life history. Some species which are numerically abundant in polluted area have this nature. For example, capitellid polychaete *Capitella capitata* (GRASSLE and GRASSLE, 1974; WARKEN, 1976; TSUTSUMI and KIKUCHI, 1984) and semelid mollusc *Theora lubrica* (KIKUCHI and TANAKA, 1976) are known as an opportunistic species. *Paraprionospio* sp. (type A) also sometimes shows extremely high density in eutrophic area, however, this type reveals not opportunistic, but fairly fixed life history. Type A can flourish eutrophic environment probably because this type has the high tolerable ability to low oxygen concentration and because the settlement occurs in the period advantageous to this type. In the present study, an experiment on the tolerance to low oxygen concentration in type A could not be made. There are, however, some supporting evidences for high tolerable ability of type A to low oxygen concentration. In Kumihama Bay, a large number of the pelagic larvae of type A were found in the water mass where the content of dissolved oxygen was less than 10% in saturation (YOKOYAMA, 1982). In Osaka Bay, many individuals of type A settled during the period of oxygen deficiency in summer. It is also important for the prosperity of type A that the settlement period of this type coincides with the declining period of many other species. This coincidence is of advantage to type A as regards the assurance of food and habitat for this type. Type A has a good adaptation to eutrophic environments in regard to both physiological tolerance and the timing of the settlement.

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日本産 *Paraprionospio* 属（多毛類：スピオ科）4型の形態と生態

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よく知られた富栄養化海域の指標種 *Paraprionospio pinnata* (EHLERS, 1901) を形態的，生態的に研究した。従来単一種として取り扱われていた我が国の *P. pinnata* は外部形態，分布，生息場所選択からみて，それぞれ種として認識される4型（A，B，CI，CII）に分けることができた。これまでほとんど，または全く取り扱われていなかった多くの形質が形態区分に有効である。A型は水深20m以浅の沿岸域に，B型は閉鎖性の強い内海の泥～砂泥底域に，CI型は内湾奥から外海に至る種々の海域に，そしてCII型は外海砂泥底域にそれぞれ分布する。4型のうちA，B両型のみが富栄養化海域で高密度または高比率の分布を示す。これら2つの型は基本的にはいずれも寿命1年で，比較的固定化された生活史を持ち，有機汚染指標種によくみられる臨機応変的な（opportunistic）生活史上の特徴は示さない。水質，底質，底生動物群集の季節変動と関連させて考えると，A，B両型は溶存酸素量低下などの富栄養化海域に特有の環境条件に対する生理的な耐性が強いことと，それに加えてA型の場合には加入着底が多数の種の減少期に起るという加入のタイミングの良いことが富栄養化海域での両型の生息，繁栄をもたらしている原因であると推定された。

Co	23	30	42	30	15	19	8	20	17	13	6	6	8	6	11	254	91.05
C	2	64	62	57	32	29	5	0	0	0	0	0	0	0	1	252	91.93
P	0	1	0	2	5	6	8	15	3	0	3	21	23	46	84	217	92.69
M	1	19	37	38	67	48	0	0	0	0	1	0	0	0	0	211	93.43
N	7	16	25	14	27	22	9	0	13	3	2	5	1	1	7	152	93.96
P	12	4	6	5	2	9	0	0	0	8	32	5	9	6	6	104	94.33
P	295	180	1	35	2	1	0	0	2	1	1	0	3	0	0	521	43.34
P	12	9	35	40	53	35	16	0	0	0	0	0	2	1	0	203	60.23
P	10	21	23	7	3	1	0	1	3	5	1	6	17	3	9	110	69.38
P	9	8	2	4	4	2	0	1	2	0	2	3	5	1	1	44	73.04
M	1	2	2	8	0	2	6	2	3	2	1	2	1	3	5	40	76.37
P	0	0	2	5	1	3	0	0	0	0	2	2	12	5	6	38	79.53
P	3	1	1	5	2	2	2	4	3	1	3	1	4	0	2	34	82.36
Cr	0	1	7	11	0	0	0	0	0	0	0	0	0	3	1	23	84.28
P	4	2	2	3	1	8	0	2	0	1	0	2	1	1	3	21	86.02
M	1	7	2	2	0	4	2	1	0	0	0	0	0	0	0	19	87.60
P	8	3	3	10	3	0	0	0	0	0	2	0	1	4	3	37	14.12
P	0	1	1	0	2	1	0	3	1	0	3	2	3	2	5	24	23.28
C	0	0	0	1	6	3	1	3	2	0	0	2	0	0	0	18	30.15
P	11	0	2	1	0	1	0	0	0	0	0	0	0	0	0	16	36.26
M	4	2	1	2	1	2	4	0	0	0	0	0	0	0	0	16	42.37
P	1	2	2	1	2	0	0	1	1	3	0	2	0	1	0	16	48.47
P	0	0	0	0	0	0	0	1	0	0	1	1	3	6	2	14	53.82
P	2	0	3	3	1	0	1	4	0	0	0	0	0	0	0	14	59.16
P	1	1	1	1	2	1	0	0	0	0	1	1	0	0	0	9	62.60
C	0	0	0	2	4	0	1	0	0	0	0	0	1	0	0	8	65.65
M	2	3	3	6	13	143	17	8	3	1	0	0	0	0	3	204	25.31
P	1	2	13	7	28	10	11	1	14	3	3	2	0	1	2	98	37.47
P	0	1	7	2	9	18	0	0	2	0	0	2	2	6	2	51	43.80
P	1	1	4	2	3	1	4	2	0	0	10	6	5	7	4	50	50.00
P	6	6	3	2	5	3	2	3	6	1	2	2	0	1	0	42	55.21
P	3	4	11	0	4	3	5	0	2	0	0	0	0	1	0	33	59.31
C	1	2	4	2	2	1	2	1	6	2	1	1	1	1	0	27	62.66
Co	0	1	1	6	2	4	4	0	0	0	1	0	0	0	0	19	65.01
P	1	3	2	3	4	4	0	0	0	0	0	0	0	0	1	18	67.25
P	4	11	0	0	0	0	0	0	0	0	0	0	0	0	0	15	69.11
P	0	1	0	3	2	0	0	1	0	0	2	0	1	2	0	12	
P	7	11	12	16	2	21	0	2	4	6	2	3	5	3	10	104	12.31
P	9	5	22	6	3	6	0	2	4	3	5	7	0	3	1	76	21.30
C	1	0	45	0	1	10	0	0	0	0	0	0	0	0	0	57	28.05
M	0	0	0	15	23	6	8	1	0	0	0	0	0	0	0	53	34.32
C	0	3	0	8	8	3	8	5	5	1	1	2	2	2	0	48	40.00
Co	1	5	10	7	0	16	0	1	0	0	0	0	1	4	1	46	45.44
P	0	1	9	7	0	14	0	0	1	3	0	0	1	0	1	37	49.82
P	3	4	2	1	0	2	0	2	1	1	4	5	1	5	0	31	53.49
P	1	2	11	3	0	2	0	0	0	0	1	2	1	0	1	24	56.33
P	0	0	5	1	0	7	0	5	0	1	0	0	0	0	5	24	59.17

imens of numerically abundant species at Stn. L in Tosa Bay from April 22, 1980 to July 8, 1981.
vs the number of specimens per $0.2m^2$. Taxonomic groups are abbreviated as: Cr; Crustacea, M; Mollusca, N; Nemertinea, P; Polychaeta.

1980									1981						Total	Cumulative Percentage
pr. 22	May 28	June 30	July 28	Aug. 25	Sept. 25	Oct. 27	Nov. 26	Dec. 23	Jan. 14	Feb. 18	Mar. 5	Apr. 8	May 13	June 8	July 8		
0	0	0	0	0	0	0	160	52	52	20	19	22	0	0	0	325	11.99
31	56	59	54	16	3	1	1	7	12	7	8	2	7	2	2	268	21.87
4	10	87	33	10	4	0	0	5	21	35	10	0	6	0	2	227	30.25
19	4	2	1	10	0	0	0	2	14	23	24	19	2	2	47	169	36.48
29	3	13	16	1	1	0	1	15	20	0	4	3	12	7	7	132	41.35
38	14	15	10	17	5	7	0	2	5	3	7	0	0	0	0	123	45.89
4	0	0	0	18	1	10	6	5	7	6	10	4	5	2	15	93	49.32
16	19	5	16	11	6	1	0	3	6	3	0	1	1	0	1	89	52.60
0	4	3	5	0	1	5	18	7	2	0	10	4	1	10	13	83	55.66
5	10	2	3	0	1	0	12	8	2	0	2	7	6	2	15	75	58.43
9	3	1	8	35	11	0	1	0	1	2	1	1	1	0	0	74	61.16
5	6	8	11	6	11	0	0	0	1	1	0	1	0	0	2	52	63.08
1	0	5	1	17	2	0	8	7	2	0	2	1	1	2	0	49	64.88
3	2	0	6	9	3	0	2	1	0	3	3	9	5	1	1	48	66.65
5	7	19	7	2	1	0	0	1	0	1	2	1	1	0	0	47	68.39
0	0	0	0	0	0	0	13	13	0	0	0	0	0	11	2	39	69.83
1	4	11	4	0	0	0	0	1	2	3	3	0	5	2	1	37	71.19
15	4	2	4	0	0	0	1	3	2	4	0	0	1	0	0	36	72.52
4	1	0	5	3	0	1	1	2	2	6	5	1	2	0	2	35	73.81
22	0	5	3	0	0	0	0	0	1	0	3	1	0	0	0	35	75.10