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ECOLOGY AND BIOLOGICAL PRODUCTION OF LAKE NAKA-UMI AND ADJACENT REGIONS

3. MACRO-BENTHIC COMMUNITIES OF LAKE SHINJI-KO AND LAKE NAKA-UMI[1)]

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With 6 Text-figures and 10 Tables

Present study deals with the macro-benthic fauna of two brackish waters which are located along the Japan Sea coast of western Honshu. The survey was carried out as a part of synthetic survey of biological productivity of Lake Naka-umi and adjacent waters by the research group directed by Prof. D. MIYADI, Kyoto University.

Hydrographic conditions of these brackish lakes much varied from season to season and seasonal change of benthic fauna seemed to be conspicuous. In the past, MIYADI (1932) and UENO (1943) studied benthic macro-fauna of Lake Shinji-ko, MIYADI et al. (1945, 1952, 1954) studied that of Lake Naka-umi and Miho Bay. Earlier surveys were mostly made only in one or two seasons. In the present study, sampling was carried out in four seasons, and some informations were obtained about the seasonal change of benthic communities. Moreover, hydrographic conditions of these lakes have much varied in these several ten years by the influence of repairment works of waterways which connect two brackish waters to the sea. Two studies cited above, which dealt with the benthic fauna of Lake Shinji-ko, have reported much different hydrographic conditions and benthic fauna. Recently, a big reclamation project is intended in this district, and Lake Shinji-ko is expected to be a fresh water lake after its accomplishment. Therefore, the survey at present stage of benthic fauna of these waters are very interesting.

Before going further, the author wishes to express his grateful thanks to Prof. D. MIYADI who was the director of the research group, and all members of the group, especially Prof. S. MORI, Otsu Hydrobiological Station, Dr. E. HARADA and Dr. H. KAWANABE, Department of Zoology, Kyoto University. He is also indebted to Dr. T. HABE, National Science Museum, for his valuable advice and identification of materials.

1) Contribution from the Amakusa Marine Biological Laboratory, No. 175.

Method

The Ekman-Birge grab was used for sampling of the bottom animals. Covering area of single sampling is $1/50\,m^2$, and four samples were taken at each station. The animals were sorted out of deposite immediately after the sampling, by a sieve with 1 mm mesh screen, and were kept in formalin to make identification and weighing in the laboratory. To estimate the quantity of phytal animals and benthos in submerged vegetation, basket quadrat sampling was carried out. Sea weeds in $1/25\,m^2$ were covered by wire-net basket and they were cut off near bottom surface and taken into the basket. Collected sea weed samples were opened in the sieve mentioned above, and animals attached on them were sorted out. Benthic animals in the bare bottom of littoral region were also collected using $1/25\,m^2$ quadrat.

Lake Shinji-ko

Description of the Study Area

Sampling was carried out in every season in 1959 (26, Apr., 1959; 2, Aug., 1959; 19, Oct., 1959 and 21, Jan., 1960) at ten fixed stations (Figure 1) coincided with the survey of other biological items. Adding to that suppli-

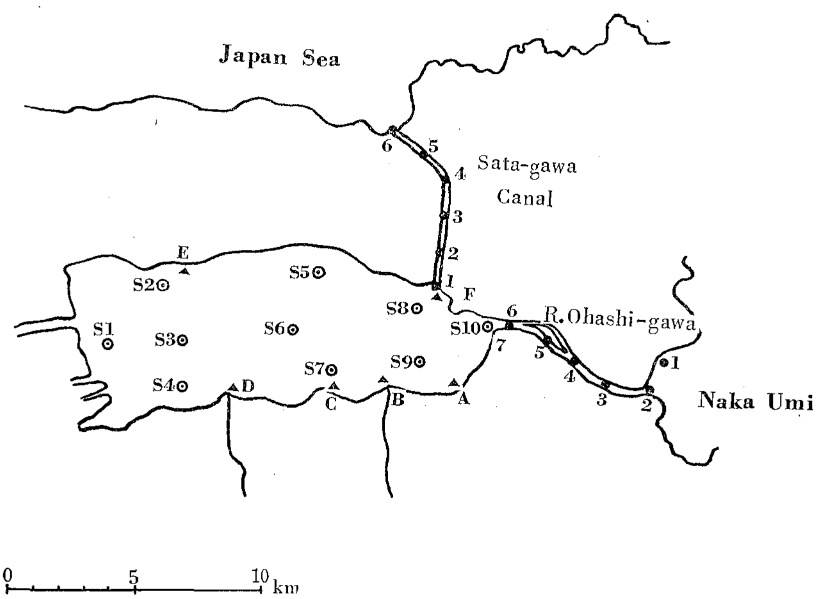

Figure 1. Map of Lake Shinji-ko and two water-courses which flow out of the lake, showing the position of sampling stations. Double circles show the fixed stations for Ekman-Birge grab sampling; triangles along the coast line show the stations for basket quadrat sampling in submerged vegetation.

mentary survey was carried out at three stations (at S 4, S 6 and S 10) in May 1960.

The Lake can be divided into two parts, marginal sublittoral region and spacious flat profoundal region. Sublittoral slope is gentle on east side, but it is narrow and rather steep along all other coasts. Two stations, S 3 and S 6 are located in the central part of lake basin and represent the profoundal region, and other stations are located in sublittoral region. Good quantity of dead leaves and roots of terrestrial grasses have been deposited on muddy bottom at S 1 at the mouth of River Hii-kawa. The substrate of northern and western coasts are muddy, but those of southern and eastern coasts, represented by S 7 and S 9, are sandy. At S 10 which is settled at the upper mouth of River Ohashi-gawa, shallow part along the coast of both sides are sandy, but middle part of waterway is deep and of hard clay bottom, the latter condition being caused seemingly by artificial excavation. The data of main environmental factors at bottom layer are given in Table 1. Chlorinity was highest in summer, and gradually decreased in cooler seasons and became

Table 1. Hydrographic conditions of bottom water at the sampling stations in Lake Shinji-ko.

April 1959

Station	1	2	3	4	5	6	7	8	9	10
Depth (m)	3.8	2.8	5.8	5.2	2.9	5.3	2.8	3.0	3.9	5.0
Chlorinity (‰)	0.62	0.66	2.10	0.60	0.72	0.75	0.70	0.71	0.77	0.86
Dissolved O_2 (cc/l)	6.48	6.68	4.40	6.74	6.74	6.88	6.74	6.64	6.71	6.73
Saturation % of dissolved O_2	92	96	62	97	97	99	98	96	90	100
pH	7.1	7.1	6.8	7.0	7.1	7.2	6.9	7.2	7.1	7.2
Water temp. (°C)	16.02	16.41	15.72	16.33	16.53	16.31	17.14	16.79	14.86	17.86
Mud temp. (°C)	16.2	16.8	14.6	15.8	16.5	15.6	16.6	17.2	16.5	17.5
Air temperature	—	22.6	24.0	23.0	25.00	23.1	22.5	22.5	21.5	—

August 1959

Station	1	2	3	4	5	6	7	8	9	10
Depth (m)	2.1	3.7	6.0	3.0	3.9	5.5	3.8	3.1	3.4	1.5
Chlorinity (‰)	1.21	1.16	3.35	1.26	1.26	2.66	1.31	1.36	1.36	2.61
Dissolved O_2 (cc/l)	6.08	4.37	1.75	2.27	4.32	3.63	4.99	4.88	4.16	4.75
Saturation % of dissolved O_2	112	79	31	41	77	67	91	88	76	88
pH	7.5	6.8	6.5	6.5	6.8	7.2	7.7	7.3	7.4	7.8
Water temp. (°C)	30.05	29.30	27.44	29.60	28.30	30.20	30.30	28.88	30.00	30.60
Mud temp. (°C)	29.4	29.0	26.5	28.4	28.5	29.2	30.0	28.7	30.4	29.0
Air temp. (°C)	32.2	33.1	33.9	32.1	31.8	32.0	30.8	31.2	31.4	30.2

(Table 1, continued)

October 1959

Station	1	2	3	4	5	6	7	8	9	10
Depth (m)	4.6	3.5	6.1	5.1	4.0	6.2	4.0	3.5	3.4	7.0
Chlorinity (‰)	1.05	1.06	1.08	1.12	—	1.11	1.15	1.05	1.12	1.12
Dissolved O_2 (cc/l)	6.41	6.18	6.36	6.43	4.17	5.75	5.47	4.89	5.12	—
Saturation % of dissolved O_2	95	91	94	95	—	86	81	72	76	—
pH	7.45	7.4	—	—	7.5	7.65	7.5	7.8	7.5	7.7
Water temp. (°C)	18.07	17.65	17.88	17.96	18.07	18.27	18.24	17.35	18.05	18.40
Mud temp. (°C)	18.0	17.6	18.6	18.0	17.9	18.9	—	21.8	17.8	18.4
Air temp. (°C)	18.2	17.9	14.6	17.9	17.4	18.8	18.5	15.5	18.9	18.4

January 1960

Station	1	2	3	4	5	6	7	8	9	10
Depth (m)	4.4	4.7	6.0	4.8	4.2	5.5	3.1	3.0	4.2	6.4
Chlorinity (‰)	0.65	0.92	0.84	1.59	1.01	0.96	0.87	1.06	1.02	1.03
Dissolved O_2 (cc/l)	11.14	11.13	11.11	11.64	8.86	8.79	11.02	8.69	11.45	11.52
Saturation % of dissolved O_2	127	129	127	134	101	100	127	101	130	131
pH	7.5	7.5	7.4	7.5	7.4	7.3	7.5	7.3	7.5	7.4
Water temp. (°C)	5.83	5.82	5.60	5.90	5.80	5.78	5.98	5.81	5.70	5.93
Mud temp. (°C)	6.0	6.4	6.9	6.2	—	7.0	6.0	6.2	6.0	6.0
Air temp. (C°)	6.2	6.1	—	6.0	5.7	6.4	5.7	6.5	4.7	4.2

lowest in spring. This must be caused by the seasonal fluctuation of precipitation and rise of water level of the Japan Sea in summer. Concerning the dissolved oxygen, surface water was saturated throughout the year, however it decreased in bottom layer of profoundal region in summer and saturation percent reached 31% in summer at S 3. Stratification of water in Lake Shinji-ko was not serious and disappeared in autumn.

Benthic Communities

Regional difference of benthic communities: The results of the survey are shown in Table 2. Japanese marsh clam *Corbicula japonica* PRIME was distributed widely and occurred at all stations of sublittoral region. Its density was especially high at south-eastern coast S 7 and S 9. Variation of density among four samples at a station was small and estimated density per 1 m^2 seems to be reliable. On the other hand, benthic fauna of profoundal region consisted of larvae of *Chironomus plumosus* and a kind of tubifaecid worms, and *Corbicula japonica* was scarcely collected. *Chironomus* larvae and *Tubifex* sp. were also collected at several sublittoral stations with muddy bottom, though their density was low. These *Chironomus* larvae and *Tubifex* sp. seemed to distribute over whole area of the muddy level bottom. A brackish isopod *Paranthura* sp. was found at S 2, and a brackish polychaete *Notomastus*

Table 2. Density and standing crop of benthic animals in Lake Shinji-ko. Upper figure shows density (N/m^2), and lower figure shows fresh biomass ($gr./m^2$).

	Animals \ Station	1	2	3	4	5	6	7	8	9	10
April	*Corbicula jap.*	75.0 (284.0)	32.5 (861.3)		100.0 (130.0)	75.0 (108.8)	425.0 (8.75)	700.0 (1147.5)	112.5 (322.5)	312.5 (641.3)	87.5 (275.0)
	Chironomus pl.				12.5 (0.25)				112.5 (2.5)		
	Tubifex sp.	25.0 (0.41)	12.5 (0.20)						62.5 (1.25)		
	Paranthura sp. (Isopoda)		12.5 (0.25)								
	Melita koreana (Amphipoda)		50 (0.05)								
	Notomastus sp.								12.5 (0.05)		
	Undetermined Nemertini				50 (—)						
August	*Corbicula jap.*	25.0 (165.0)	75.0 (132.5)		100.0 (311.3)	112.5 (301.3)	12.5 (13.75)	987.5 (1726.3)	104.1 (52.5)	312.5 (671.3)	125.0 (225.0)
	Chironomus pl.				50.0 (1.0)		262.5 (5.63)				
	Tubifex sp.		87.5 (1.87)				12.5 (0.26)				
	Melita koreana										12.5 (—)
	Dragon fly* larva		12.5 (10.0)								
October	*Corbicula jap.*	62.5 (12.5)	126.3 (28.8)		112.5 (160.0)	75.0 (422.5)		337.5 (533.8)		112.5 (176.3)	25.0 (63.75)
	Chironomus pl.			887.5 (4.58)			37.5 (0.88)				
	Tubifex sp.	12.5 (0.25)					62.5 (1.25)				
	Paranthura sp.		62.5 (0.75)								
January	*Corbicula jap.*	50.0 (45.6)	25.0 (53.1)		75.0 (264.4)	50.0 (62.5)		100.0 (455.6)	100.0 (187.5)	62.5 (123.1)	—
	Chironomus pl.			125.0 (3.13)			12.5 (0.25)				
	Tubifex sp.	275.0 (2.63)		50.0 (0.25)	37.5 (0.63)						
	Paranthura sp.		25.0 (0.25)								

* Dragon fly···*Ictinogomphus clavatus* FABRICIUS.

sp. was collected at S 8 in April 1959, but they were low in density. Other two species of small polychaetes were collected at S 10 in May 1960, one of them seemed to be *Prionospio japonica* which was described by OKUDA (1935) from several brackish lakes along the Japan Sea coast of western Honshu, but another sedentary species is not identified. A Cumacean Crustacea which was collected at S 6 at the same time was new to science, and it was described by GAMÔ (1962) as *Leucon simanensis*.

As the fixed sampling stations were restricted in sublittoral and profoundal region, sampling of benthic animals and phytal animals of water weeds in littoral region was carried out in May 1960. The result is shown in Table 3. *Corbicula japonica* was found at most localities and the densities were higher than those of sublittoral region.

Table 3. Benthic and phytal animals in littoral region of Lake Shinji-ko, at the sampling in May 1960.

Station*	A	B	C	D	E	F	F'**
Depth (m)	0.15	0.2–0.4	0.2	0.3	1.0–1.2	1.2	1.0
Substratum	S. & Gr.	cS	S. & Gr.	S	Rock	M	—
Potamogeton malaianus	+		+	+	+		
P. perfelitus			+				
Mylliophyllum spicatum				+			
Zostera nana				+		+	
Cladophora sp.			+			+	+
Calogrossa ogasawaraensis							+
Compsopogon oishu							+
Corbicula jap.	312 (1100)	0	243.5 (462.5)	387.5 (988.1)	0	320.0 (1760.0)	—
Corbicula jap. (juvenile)	8 (0.12)	0	0	6.25 (0.05)	0	384 (3.85)	—
Clithon retro.	32	0	25	6.25	0	0	—
Assiminea jap.	0	0	12.5 (0.44)	43.75 (15.63)	0	0	—
Total Crustacea***	280 (0.96)	0	68.75 (0.44)	43.75 (0.62)	0	0	384 (0.38)
Dipterous larvae	0	0	6.25 (0.12)	0	0	0	—

*) Sampling stations are shown in Figure 1.

**) This sample was collected from a clump of algae attached on a stem of *Phragmates communis* in swamp. Wet weight of a clump of *Cladophora* examined was about 180 gr.. Neigher the alga nor animals were evaluated on an area basis.

***) Crustaceans consist of three species of amphipods *Grandidierella japonica, Melita koreana* and *Annisogammarus annandalei*, and two species of isopods *Neosphaeroma oregonensis*, *Paranthura japonica* and *Tanais* sp..

A snail *Clithon retropictus* was very common on stones or wooden posts along the whole shore line of the lake, but its lower limit of vertical distribution was about 0.5 m. Small Crustacea, except *Paranthura* sp. which lived in sandy bottom, are phytal animals and their distribution was restricted by that of water-weeds.

Seasonal change: The density of marsh clam *Corbicula japonica* was highest at S 7 and S9 in south coast in spring and summer, however, it decreased greatly in autumn and winter. Density at other stations did not show distinct seasonal change, so the decrease of average density in those seasons is mostly due to the decrease at two stations. A big quantity of *C. japonica* are collected by fishermen (according the fishery statistics by the Shimane Prefectural Government, annual catch of the clam from Lake Shinji-ko in 1959 reached more than 3000 tons in fresh weight with shell), and the main fishing ground is sandy sublittoral region of eastern half of the lake. The decrease of population in that area seemed to be caused by the fishing. According to MIYAZAKI (1936), the spawning season of *Corbicula japonica* is once a year and larvae spend planktonic life just like that of marine pelecypods. In plankton samples collected at the same time with present study, veliger larvae of *Corbicula japonica* were found in summer, and their appearance was restricted to eastern half of the lake (YAMAZI, unpublished). Though real age of the clam was not determined exactly, most of individuals collected were 1 or 2 years old according to growth rings and size—frequency distribution, and juveniles and big ones older than 3 years were very rare. The absence of juveniles may be explained by the difference of habitat preference between juveniles and adults. YAMAMOTO (1955, 1959) reported the disagreement of habitat between juveniles and adults of the clam at Lake Hachiro-gata and a river which opens in Matsushima Bay, and he ascertained that the disagreement was based on the difference of physiological tolerance of juveniles and adults to salinity condition. He reported that juvenile clam was less resistant to both hyper- and hypotonic conditions, and the habitat range of adult extended to the area of both higher and lower salinity conditions. In Lake Shinji-ko, juvenile clams were found in high density only at sublittoral region near the mouth of River Sata-gawa. Total biomass of *Chironomus—Tubifex* community in profoundal region reached maximum in spring, in spite of the highest density in autumn. No benthic animals were collected at S 3 both in spring and summer. Some *Chironomus* larvae were collected at S 3 by a small PETERSEN's trawl in spring, but no animal was collected by any sampling methods in summer. This absence of benthos in summer seemed to be caused by the high salinity and low dissolved oxygen content of bottom water at the station. In autumn, many small larvae of *Chironomus* (average body weight of which is 4 mg in fresh weight) appeared with a few large one (average body weight of which is 20 mg) at S 3.

Standing crop: The seasonal change of average density and average biomass of benthos were calculated. Quantity of *Clithon retropictus* in littoral region was not evaluated but its distribution area is so small that it can be neglected in macroscopic consideration. Small phytal animals were also neglected, for the total area of submerged vegetation in the lake was small, and even in the submerged vegetation, biomass of those animals was rather small. Average density of *Corbicula japonica* in sublittoral stations was calculated from the data of seven stations. S 10 which is located at the mouth of River Ohashi-gawa is excluded, because of the big variance of depth, substratum and amount of animals by a little shift of sampling point. The average density of *Corbicula* in four stations of littoral region in spring was

Table 4. Rough estimate of total standing crop of macro-benthos in the Lake Shinji-ko.

Sublittoral region ($18\,km^2$)

Corbicula japonica	Spring	Summer	Autumn	Winter
Average density (N/m^2)	242.8	223.2	132.2	89.8
Average wet weight with shell ($gr./m^2$)	498.5	480.1	190.5	191.4
Estimated total biomass in wet weight with shell (tons)	9000	8600	3400	3400
Estimated total biomass in dry weight without shell (tons)	540	520	200	200

Profoundal region ($64\,km^2$)

Chironomus larvae	Spring	Summer	Autumn	Winter	Spring
Average density (N/m^2)	162.5	78.1	250.0	43.5	136.5
Average wet weight ($gr./m^2$)	3.25	1.56	1.41	0.87	2.71
Tubifex sp.					
Average density (N/m^2)	21.8	25.0	15.0	72.5	30.0
Average wet weight ($gr./m^2$)	0.39	0.43	0.30	0.70	0.54
Chironomus + *Tubifex* sp.					
Average wet weight ($gr./m^2$)	3.64	1.99	1.71	1.57	3.25
Estimated total biomass in wet weight (tons)	233.0	127.4	109.5	100.5	208.5
Estimated total biomass in dry weight (tons)	44.3	24.0	20.8	19.1	39.5
Whole area of the lake ($82\,km^2$)					
Estimated total biomass of macro-benthos in dry weight (tons)	584.3	544.0	220.8	219.1	

315.8m^2 and higher than that of sublittoral region in the same season. Average density of *Chironomus—Tubifex* community was calculated from S 3 and S 6 in profoundal region and two sublittoral stations S 4 and S 8 at which those animals occurred. According to the data in Lake Mogoto-numa by ASAHINA (1942) and in Lake Jusan-gata by TAMURA (1953) and by FUJI (1955), the lower limit of vertical distribution of *Corbicula japonica* seemed to be 1.5 to 2.9 m, however most of the clam aggregated in littoral region less than 0.5 m. ASAHINA (1942) mentioned the high oxygen demand of the clam and presumed the low oxygen content in deep water must be the limiting factor of vertical distribution of the species in Lake Mogoto-numa. On the other hand, considerable quantity of *Corbicula* distributed in sublittoral region deeper than 4 m in Lake Shinji-ko. The border of profoundal and sublittoral region was considered to be represented by 4 m line from the topography of the lake basin and distribution of benthic animals. According to the chart, total area of littoral and sublittoral region of the lake is about 18 km^2. At the lowest estimate, average density of sublittoral stations was used for estimation of total standing crop of whole area of the lake. Estimation of total biomass of *Chironomus—Tubifex* community in profoundal region was carried out in the same way. Area of profoundal region is about 64 km^2. Estimated total standing crop in each season are shown in Table 4.

Two Water Courses Between Lake Shinji-ko and High Saline Waters

Lake Shinji-ko is connected with saline waters by two water-courses. Main path is River Ohashi-gawa which flows out from east end of the lake and opens to Lake Naka-umi. The other one is the Sata-gawa Canal which flows out from north-eastern side of the lake, and it directly opens in the Japan Sea. Difference of water level between Lake Shinji-ko and Lake Naka-umi or the Japan Sea is small, and salt water easily comes up at full tide. As the faunas of Lake Shinji-ko and of higher saline waters are much different, transition of benthic fauna in two watercourses were examined in August and in January in 1960. The results are summarized in Table 5. *Zostera nana* and *Potamogeton perfeliotus* grow in littoral zone of lower half of River Ohashi-gawa, but no water weed was found in the Sata-gawa Canal. Though the distribution of small crustaceans which were phytal animals was influenced by presence or absence of submerged plants, they were common both in Lake Shinji-ko and in Lake Naka-umi. Sampling stations were shown in Figure 1. Japanese marsh clam *Corbicula japonica* is distributed at the river mouth of both water-courses. A living specimen of *Macoma incongrua* was collected at st. 7 of the Sata-gawa Canal, and shell remain of the species was also collected at Ô-i, Makata and N 5 off Makata. In River Ohashi-gawa, those species which originated in shallow bottom community of Lake Naka-umi such as *Musculus senhousia*, *Fluviocingula nipponica*, *Stenothyra edogawaensis* and *Platynereis aggassizi*, all disappeared between st. 3 and st. 5. The chlorinity gradient did not show conspicuous change in the middle part of River Ohashi-gawa, but biological border of two brackish waters must be settled around st. 4.

Table 5. Distribution of macro-benthos in River Ohashi-gawa and in the Sata-gawa Canal.

1) River Ohashi-gawa

Station		1	2	3	4	5	6	7
Chlorinity of bottom	Aug.	—	13.02	10.79	11.07	10.02	9.58	9.86
water (‰)	Jan.	—	7.86	1.87	1.89	1.22	—	1.21
Musculus senhousia		+++	+	+	++			
Fluviocingula nipponica		++	+	+				
Stenothyra edogawaensis		+	+	+				
Assiminea japonica			++	+++	++	+		+
Clithon retropictus			+	++	++	+		++
Corbicula japonica			++	++	+	+	+	++
Cleantis planicauda		+	+		+			
Paranthura sp.				+				+
Neosphaeroma oreg.			+	+	+	+		
Amphipods*		+	+	+	+	+		
Neomysis japonica				+				
Platynereis sp.		+	+	+				
Notomastus sp.					+++			
Prionospio japonica								+
Number of species		6	10	11	7	5	1	6

* Amphipods consisted of *Ampithoe valida*, *Anisogammarus annandalei* and *Grandidierella japonica*.

2) Sata-gawa Canal

Station		1	2	3	4	5	6
Chlorinity of bottom	Aug.	2.23	1.82	1.73	2.02	2.10	2.451
water (‰)	Jan.	1.28	1.28	1.27	1.92	—	6.91
Corbicula jap.		++	+	+	+	+	
Macoma incongrua							+
Notomastus sp.					+		
Paranthura sp.		+					+
No. of species		2	1	1	2	1	2

Lake Naka-umi

Description of the Study Area

River Ohashi-gawa opens at the western end of Lake Naka-umi and several rivers flow into the lake at the southern coast. On the other hand, it is connected with Miho Bay by the Sakai Channel at the north-eastern corner. High saline water which comes from Miho Bay and fresh or low saline water which comes from Lake Shinji-ko and rivers meet in Lake Naka-umi, therefore, the vertical stratification of water exists throughout the year. Low saline water spreads in the upper layer and high saline water distributes in the deeper layer, and discontinuity layer was found between 3 to 5 m in depth. Therefore, chlorinity of bottom water in the coastal zone shallower than this critical depth was much lower than that of deeper stations. Other environmental factors such as water temperature, dissolved oxygen and nutritive elements also showed distinct stratification. The lake is divided into two parts by two small islands; Daikon-jima and E-shima. North and west part of the lake is the main path of the currents both up- and downwards, then mixing of water was fairly good in this region and decrease of dissolved oxygen in bottom water was not serious. On the contrary, stratification of water was conspicuous in south-east region where stagnation of water was serious in summer, and dissolved oxygen in bottom water much decreased in summer and autumn.

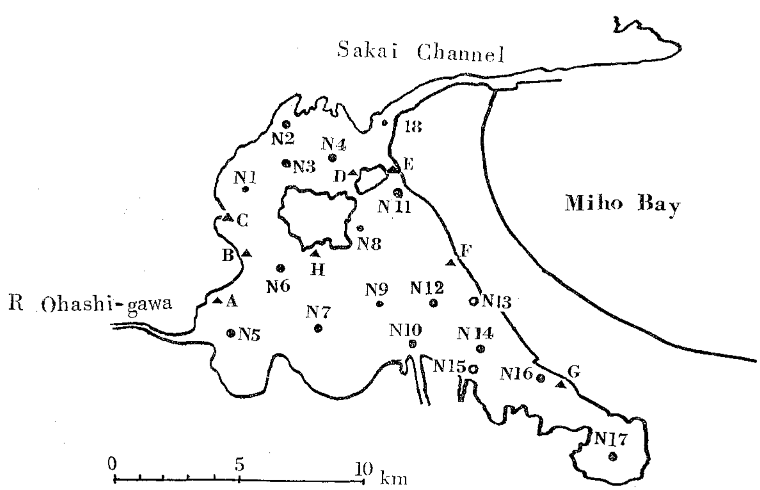

Figure 2. Map of Lake Naka-umi showing the position of sampling stations. Solid circles show the fixed stations for Ekman-Birge grab sampling; triangles show the stations for basket quadrat sampling in submerged vegetation.

The environmental conditions of bottom layer at sampling stations are shown in Appendix Table 1.

Sampling was carried out in four seasons in 1959 (27, Apr., 1959; 31, Jul., 1959; 21, Oct., 1959 and 20, Jan., 1960). Eighteen stations were settled at the first survey, but two stations, N 13 and N 15, were omitted from the second survey. The map of Lake Naka-umi showing sampling stations for Ekman-Birge grab sampling and for basket quadrat sampling are illustrated in Figure 2. Supplimentary survey of grab sampling was carried out at five stations which represent different habitat conditions (N 3, N 9, N 16, N 18 and N 19). Environmental situations of these stations are shown by the combinations of physical

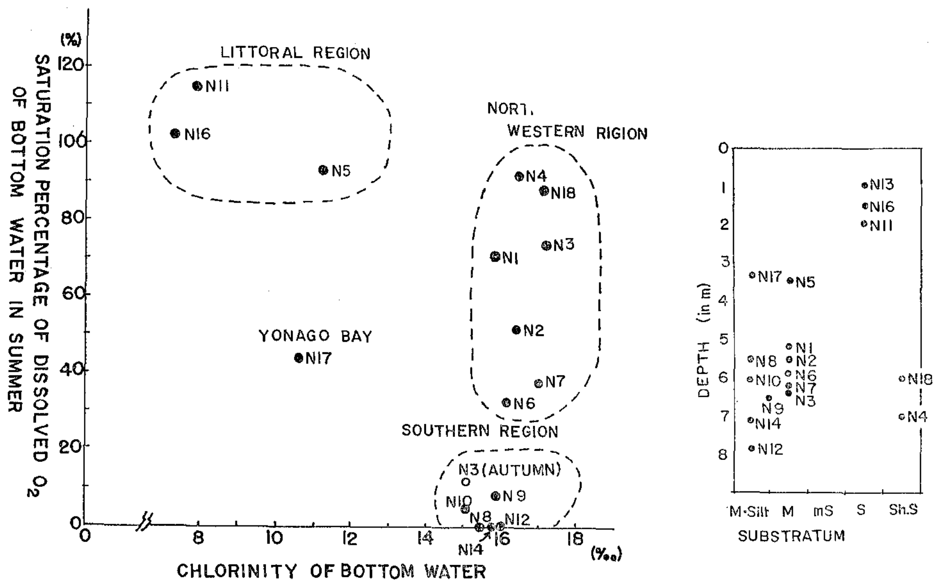

Figure 3. Environmental situations of sampling stations in Lake Naka-umi.

or chemical factors. Taking the gradients of chlorinity and saturation percent of dissolved oxygen concentration in summer on two axes, stations can be plotted as is shown in Figure 3. Grouping of plots in the figure corresponds to three topographical regions. Depth and texture of substratum of thes tations are also shown in the figure.

Benthic communities

Regional distribution of benthic communities and shell remains: The results of the survey are shown in Appendix Table 2. At first, similarity of community composition among sampling stations was examined using the data of spring which is the most favourable time for benthic animals. Shell remains deposited on the bottom are also very good indicators of biological characteristics of the area (MIYADI et al., 1945, HABE, 1956), similarity in them among stations were also examined. Calculation is based on the total of four samples collected at a station in spring 1959. As a measure of comparison MORISITA's community similarity indices C_λ and $C_{\lambda(w)}$ was used. The former index is based on numbers of species and of individuals and the latter is on them and biomass. These indices become 1 when the composition of two samples are identical, and become 0 when they have no common component (MORISITA, 1959). As the samples of benthos in N 8 and N 15 were few (less than 0.5 gr. in total biomass), calculation of index of similarity of living benthos at those stations were omitted. The results are shown in Table 6. In conclusion, stations are divided into two distinct groups and some transient stations. The first group consists of N 11, N 13 and N 16 which was located on shallow sandy bottom along the Yumi-ga-hama beach. The bottom of these stations were covered by eel grass *Zostera marina* and *Z. nana*, and a filamentous alga *Ectocarpus* sp.. Dominant benthic animals of this region were *Musclus senhousia* and *Fluviocingula nipponica*, accompanied by *Stenothyra edogawaensis*, *Didontoglassa koyasensis*, *Macoma incongrua* and *Pectinaria* sp. In spite of the difference of texture of substratum, similar community was found at N 5 at the mouth or River Ohashi-gawa and an odd station in the sublittoral region off Honjo on the west coast. This community may spread over whole area of shallow low saline region. *Musculus senhousia* were also found in quantity on rocky substratum of the north coast (near Tasumi, Watata-hana Point, Miyagahara Point), north coast of Daikon-jima Island and south-eastern coast (Minat-yama in Yonago Eay and Aburatsubo-hana Point). Another group contains N 7, N 9, N 12 and N 14 in south region. Though the similarity index values were low owing to the low density of animals, N 8 and N 10 should be attributed to this community. These stations were deeper than 6 m and dissolved oxygen of bottom water at these stations much decreased in summer. Benthic fauna of this region consisted of three species of pelecypods, *Raeta pulchela*, *Theora lubrica* and *Musculus senhousia*, and of a polychaete, *Prionospio pinnata*. Except juveniles of *Musculus* which spreaded over whole area of the lake, three species were much resistant to lack of dissolved oxygen, and HABE (1956) pointed out this *Raeta pulchela—Theora lubrica—Prionospio pinnata* community as the characteristic benthic fauna of temporal stagnated region. These species are also spreaded in west region, however, these stations are characterized by existence of *Anadara subcrenata*, *Venemolpa micra*, three species of tunicates (*Styela plicata*, *Ciona intestinalis* and other one species), two species of sea-pens (*Scytalium sprendens* and *Cavernularia obesa*) in spring. Owing to the large size and low density, only a few of them were collected by small Ekman-

Table 6. Similarity of community composition of benthic animals and shell remains among the stations. Calculation of the index of similarity is based on the samples collected in April, 1959.

A. Macro-benthic animals

St. \ St.	18	16	13	11	15	5	17	4	2	1	6	3	7	9	14	12	8	10
10	.12	.04	.05	.00	—	.18	.07	.00	.00	.35	.30	.28	.78	.96	.83	1.06	.24	
8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
12	.00	.00	.00	.00	—	.00	.00	.00	.16	.15	.12	.82	.96	.72	.95			
14	.00	.00	.00	.00	—	.00	.00	.00	.22	.18	.12	.02	.82	.74				
9	.19	.09	.06	.09	—	.67	.01	.00	.47	.88	.67	.20	1.10					
7	.38	.16	.00	.00	—	.57	.19	.00	.12	.45	.25	.05						
3	.00	.00	.00	.00	—	.00	.00	.00	.11	.08	.03							
6	.21	.21	.33	.19	—	.50	.21	.49	.17	.41								
1	.00	.00	.00	.00	—	.74	.00	.00	.19									
2	.00	.00	.00	.00	—	.00	.00	.00										
4	.00	.00	.00	.00	—	.00	.00											
17	.61	.24	.08	.24	—	.67												
5	.86	.08	.30	.27	—													
15	—	—	—	—														
11	.63	.95	.91															
13	.13	.96																
16	.60																	

$$C_{\lambda(w)}=\frac{2\sum_{i=1}^{\infty} W^2 n_{1i} n_{2i}}{(\lambda_{(w)1}+\lambda_{(w)2})W_1 W_2}$$

B. Shell remain assemblages

St. \ St.	18	16	13	11	15	5	17	4	2	1	6	3	7	9	14	12	8	10
10	.01	.05	.16	.17	.58	.04	.04	.10	.07	.02	.01	.03	.06	.10	.07	.07	.10	
8	.21	.30	.24	.06	.46	.28	.29	.28	.10	.14	.20	.36	.37	.45	.77	.40		
12	.06	.08	.09	.12	.16	.01	.04	.13	.19	.09	.38	.68	.66	.53	.81			
14	.12	.09	.28	.03	.29	.08	.06	.26	.09	.11	.56	.78	.62	.84				
9	.09	.02	.12	.04	.24	.07	.39	.21	.34	.19	.77	.92	.90					
7	.07	.01	.38	.03	.17	.05	.04	.24	.54	.21	.87	.98						
3	.03	.02	.08	.04	.06	.04	.02	.65	.48	.36	.69							
6	.20	.02	.09	.02	.17	.76	.02	.63	.05	.04								
1	.07	.07	.04	.01	.20	.21	.17	.09	.17									
2	.08	.02	.05	.02	.11	.13	.01	.32										
4	.92	.02	.01	.05	.10	.02	.03											
17	.11	.57	.51	.57	.69	.87												
5	.16	.71	.76	.81	.91													
15	.13	.77	.88	.84														
11	.06	.94	.96															
13	.06	.93																
16	.02																	

$$C_{\lambda}=\frac{2\sum_{i=1}^{\infty} N_{1i} N_{2i}}{(\lambda_1+\lambda_2)N_1 N_2}$$

Birge grab sampling. Therefore, large benthos and shell remains which were collected by a small PETERSEN's beam trawl are shown in Figure 4. The result shows distinct localization of these animals in west and north regions. Some other animals, *Fulvia mutica, Dosinia angulosa* and some polychaetes restricted their distribution within the same area. Many shell remains of *Macoma incongrua* deposited in Yonago Bay (N 16 and N 17) and at the mouths of

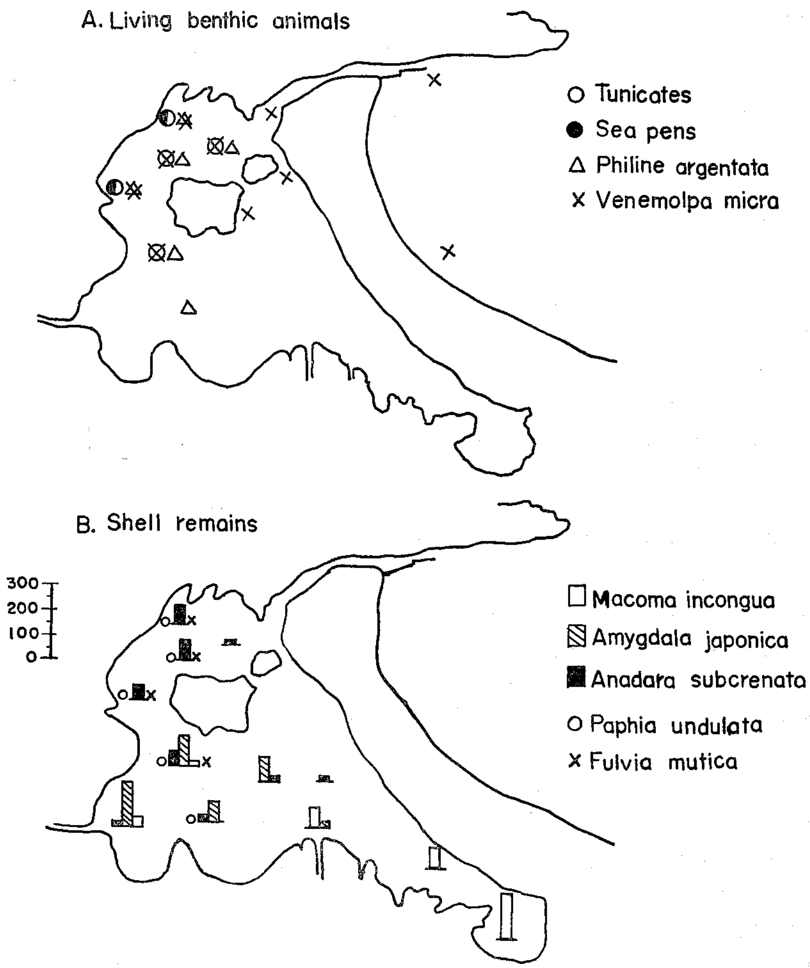

Figure 4. Distribution of some benthic animals and shell remains which were collected by a small PETERSEN's beam trawl.

River Iinashi-gawa (N 10) and River Ohashi-gawa (N 5), this species seemed to characterize the estuarine environment. Though there were only a few of a kind of polychaete *Platinereis agassizi* in grab sample at N 17, existence of shell remains of *Macoma incongrua* and tubes of *Pectinaria* sp. suggest that the area occupied by modified form of shallow bottom community previously mentioned. In Sakai Channel, bottom was covered with coarse sand containing gravels and shell remains by the effect of rapid tidal current and density of living benthos was low. At N 18 at the inner end of the channel, salinity of water was rather higher than in other parts of Lake Naka-umi, and shell remains consisted of characteristic species of weak- or middle-embayment degree such as *Microcirce directa, Nucula paulura* and *Alvenius ojianus*. The shell remains of these species were restricted to N 18 and N 4. Three species of *Ampelisca* (Crustacea, Amphipoda) and some polychaetes showed the same distribution pattern.

These groupings of benthic animal communities coincide generally with the areas defined by physical environmental factors are continuous and communities of adjacent stations which belong to different groups have rather similar compositions. N 6 and N 7 are such intermediate stations. Though saturation percentage of dissolved oxygen at N 3 was rather high in summer (74%), the bottom fauna involved considerable density of *Raeta pulchela* and *Prionospio pinnata* which were characteristic species of oxygen deficient region, and similarity index values between N 3 and south-east region, gained from shell remain assemblages, showed high similarity. This may be explained by serious lack of oxygen at that station in autumn (12%).

Seasonal change: In south-east region, well grow *Raeta pulchela, Theore lubrica* and *Prionospio pinnata* inhabited in high density in spring, but all benthos disappeared in summer at N 8, N 10, N 12 and N 14, and only *Prionospio pinnata* remained alive at N 7 and N 9. The lack of dissolved oxygen continued till autumn, and azoic area increased and biomass of *Prionospio* decreased as it grew. Adults of *Prionospio* disappeared between summer and autumn, and only juveniles were found in autumn. Numerous planktonic larvae of a kind of polychaete were collected at several stations in the south-east region in summer of 1959 and 1960. According to the personal communication from Dr. YAMAZI who studied zoo-plankton in the study group of this project, these polychaete larvae crowded at bottom water layer. Judging from their strong tolerance against lack of oxygen and rarity of other polychaetes in the region, they seemed to be the new generation of *Prionospio pinnata*. *Raeta pulchela* and *Theora lubrica* appeared again in winter, but all of them were young individuals less than 5 to 11 mm in shell length. Most of *Raeta* collected at N 9 in May 1960 were adults. Recruiting juveniles of these bivalves might have come from surrounding region of this temporally azoic area to recolonize in late autumn or in winter, and have rapidly grown up in a few months. There were many dead young shells of *Anadara subcrenata* and *Amygdala japonica* in south-east region, but no dead shells of the adult were found among them. Mode of shell length of these dead shells read from the size-frequency graph was about 8 to 10 mm. Shell remains of *Anadara* *subcrenata* of various size were found in north and west region which was favorable for the species, and mode of shell length is much larger than that of south-east region. Figure 5 shows the difference in size distribution of *Anadara subcrenata* between these two regions. Since larger shell remains, low in density, were scarcely collected by Ekman-Birge grab, while smaller ones were likely to be lost from the samples collected by the beam trawl. Figure 5 is tentatively made basing on the total materials obtained by these two. The areas of sampling by these two gears were different and the total of both samples does not give true size distribution of *Anadara* in a region, but this can be used for comparison between two regions. Distinct decrease in number of shells larger than 24 mm in the north and west region was probably related to fishing. As will be described later, this size corresponds to the minimum commersial size. This difference of size distribution between two regions should be explained that the larvae spread and settle on whole area in winter, but young shells in south-east region eventually die out in summer from lack of oxygen. As the result of repetition of this process every year numerous smaller shell remains are accumulated there. The favorite habitat of *Amygdala japonica* seemed to be western shallow part near N 5 and eastern sandy coast around N 11. The existence of young shells of *Amygdala* in stagnated region may be explained also in the same way.

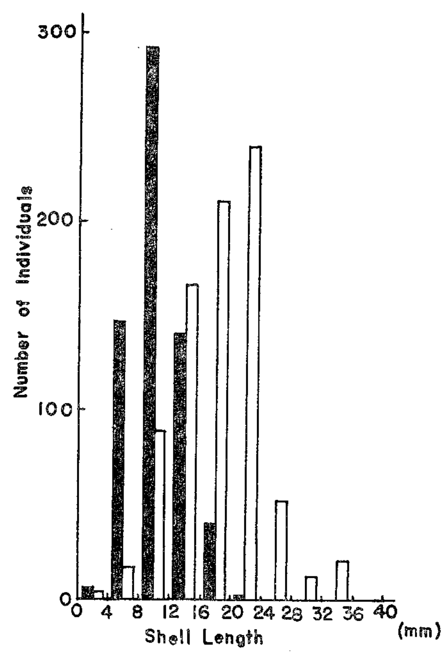

Figure 5. Size distribution of shell remains of *Anadara subcrenata*. White column shows samples collected from north and west region (N 1, N 2, N 3, N 4 and N 6), and black column shows samples collected from south-east region (N 8, N 9, N 10, N 12 and N 14).

In north and west region, living benthos were collected throughout the year. *Prionospio pinnata. Theora lubrica* and *Raeta pulchela* are also abundant in this region, and seasonal change of these species is similar to that in south-east region. Tunicates and sea pens were collected in spring and winter but not during summer to autumn. They were collected again in May 1960. *Cylichnatys yamakawai* and *Venemolpa micra* also appeared from winter to early summer and disappeared in warmer seasons. *Anadara subcrenata* spawns in summer and juveniles attached on shell remains or stones by bissus were collected in winter. This cockle is one of the important objects of fishery in Lake Naka-umi and fishing season lasts from autumn to winter. According to the distance between the teeth of fork attached at the mouth of dredge which is used as fishing gear, only the individuals larger than about 25 mm in shell length are fished selectively. As fishing intensity is pretty high, considerable portion of mortality of adults may be caused by fishing. Owing to the paucity of the data, quantitative figures on mortality can not be described. Seasonal change of shallow bottom community is primarily determined by the change of dominant species *Musculus senhousia.* This species distributed not only in *Zostera* region but also on muddy or rocky bottoms forming dense

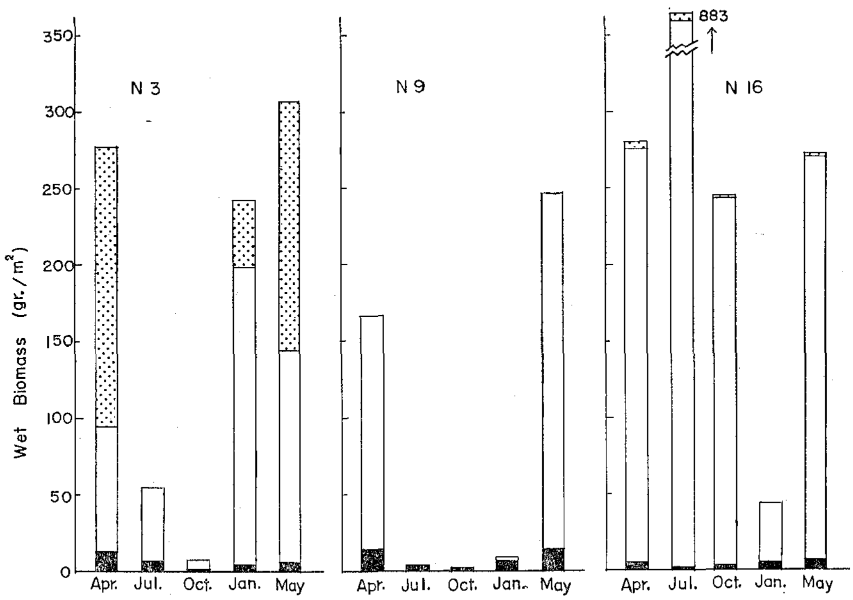

Figure 6. Seasonal change of biomass at three stations which represents three different regions of Lake Naka-umi. Black part shows polychaetes, white part shows molluscs and dotted part shows other miscellaneous animals.

aggregation. According to KATO and AKIYAMA (1959), spawning season of *M. senhousia* ranges from spring to late autumn in Lake Naka-umi, and planktonic larvae are most abundant in autumn. In the present study, much quantity of young *M. senhousia* were found on the leaves of *Zostera* and bottom surface of shallow sublittoral region in spring. However, except for the north and east coast or very shallow part of other sides, most of them died of bad water in summer or in autumn. Mortality and the time of death considerably vary from place to place. Seasonal changes of biomass at three representative stations of three regions of Lake Naka-umi are shown in Figure 6.

Standing crop: Rough estimation of standing crop of benthic macro-fauna was carried out using the data of Ekman-Birge grab sampling. At first, average biomass per unit area was determined on each community or biological region, and total biomass of these regions were calculated by multiplying average biomass by area. The boundary between shallow sublittoral region and other regions agreed generally with 2 m contour line, and the boundary between west region and south-east region coincides to the line which connects Ito-bana Point on south coast and Nyuko on south coast of Daikon-jima Island. N 18 at the inner end of the Sakai Channel was omitted at the calculation of average biomass, for the environment and composition of benthos were peculiar and area of such environmental conditions was very few. Calculated figures are shown in Table 7. Estimation of biomass of whole area from small sampling area is much uncertain, and perhaps they must be much underestimated. For example, there is a evidence of underestimation in north and west region. Distribution of a cockle *Anadara subcrenata* is restricted in the

Table 7. Rough estimate of total biomass in Lake Naka-umi which is based on the data of Ekman-Birge grab sampling.

	Region	Littoral	North and West	South	Yonago Bay	Total
Spring	Average biomass in wet weight (gr./m^2)	148.75	123.75	53.63	15.63	—
	Estimated total biomass in wet weight (tons)	1,650	4,850	2,390	100	8,900
	Estimated total biomass in dty weight (tons)	108.9	350.8	157.7	19.1	636.5
Summer	Average biomass in wet weight (gr./m^2)	21.56	4.81	2.0	0	—
	Estimated total biomass in wet weight (tons)	240	150	89	—	430
	Estimated total biomass in dry weight (tons)	15.8	10	17.53	—	53.3
Autumn	Average biomass in wet weight (gr./m^2)	4.95	1.14	+	0	—
	Estimated total biomass in wet weight (tons)	55	45	—	—	100+
	Estimated total biomass in dry weight (tons)	3.6	3	—	—	6.6+
Winter	Average biomass in wet weight (gr./m^2)	1.78	4.86	0.23	0.05	—
	Estimated total biomass in wet weight (tons)	20	190	10	0.3	220
	Estimated total biomass in dry weight (tons)	1.4	13.8	2.6	0.05	220

Notes: 1. Figures of estimates are rounded.
2. Conversion coefficients of animals from fresh weight to dry weight were borrowed from THORSON (1957).

region. According to fishery statistics by Ministry of Agriculture, annual catch of the cockle in 1958 is 104.3 tons in fresh weight, and according to actual statistics by Prefectural Government of Shimane, annual catch of the cockle in the same year is 489.0 tons and it is 4.7 times of former figure. On the other hand, total biomass of macro-benthos in north and west region in winter was evaluated only 190 tons in the present study. These figures suggest presence of far more quantity of the cockle population. To estimate the quantity of phytal animals and benthos in submerged vegetation, basket sampling was carried out in May 1960. Sampling stations were shown in Figure 2, and 2 or 4 samples were collected at each station. The lower limit of submerged vegetation ranged from 1.8 to 2.4 m in depth, on the average it can be regarded about 2 m. Then area of *Zostera* region was calculated by multiplying the cover of *Zostera* by the area of shallow sublittoral region less than 2 m in depth. According to NEGORO (unpublished), the shallow region is about 10 percent of whole area of the lake and it corresponds to about 10 km^2. The most luxuriant submerged plant was *Zostera marina* and *Zostera* region occupied about half a of the shallow sublittoral region. Cover of *Zostera* in vegetation was determined by the direct observation from running boat. The cover of *Zostera marina* was about a half of *Zostera* region and that of *Z. nana* was about 1/6 of *Zostera* region. Therefore, total area of *Z. marina* in Lake Naka-umi was regarded as $10\,km^2 \times 1/2 \times 1/2 = 2.5\,km^2$, and that of *Z. nana* was $10\,km^2 \times 1/2 \times 1/6 = 0.83\,km^2$. *Sargassum hemiphyllum* grows along the whole coast line of Lake Naka-umi, but its habitat restricted in rocky bottom and cover was only 5% of the whole shallow sublittoral region. Therefore, total area of *Sargassum* cover was estimated about 0.5 km^2. Phytal animals attached on *Zostera* consisted of gammaridean amphipods and isopods such as *Ampithoe*

Table 8. Standing crop of phytal animals in Lake Naka-umi. The data were obtained in May, 1960. The figures show biomass in wet weight, converted into gr./m^2 from original measurements.

Vegetation	*Zostera marina*					*Zostera nana*			
Locality	A	A′	C	E	Average weight	B	D	G	Average weight
Depth (m)	1.2	1.8	1.0	1.0		0.5	0.3	1.0	
M. senhousia	30.0	44.3	43.1	240.9	139.4	35.8	19.5	4.25	19.88
Crustacea	5.83	10.5	8.58	13.8	9.68	8.08	84.08	14.0	8.72

Vegetation	*Sargassum hemiphyllum*				*Ectocarpus* sp.	*Ulva pertusa*
Locality	B	B′	D	Average weight	F	H
Depth (m)	0.8	1.3	1.0		1.0	1.8
M. senhousia	131.3	+	192.0	107.40	33.9	185.0
Crustacea	33.13	72.0	258.72	121.85	14.7	14.7

valida, Melita koreana, Anisogammarus annandalei, Synidotea laevidorsalis, Idotea metalica, Neosphaeroma oregonensis etc., and adding to the species above mentioned, *Hyale grandicornis, Caprella acutifrons, C. scaura* etc., attached on *Sargassum.* Besides, many juveniles of *Musculus senhousia* attached on submerged plants. As these phytal animals were so numerous, only the biomass in wet weight was measured and the results are shown in Table 8. Wet biomass of small crustaceans were similar in two kinds of *Zostera* vegetation and ranged 8.0–14.0 gr./m^2. Though the biomass of crustanceans on *Sargassum* was far more than that in *Zostera* region, area and cover of *Sargassum* region was much less than that of *Zostera* region. Total biomass of phytal crustaceans which were calculated from the data mentioned above reach 9 tons or more in wet weight. Considering the technical limitations of basket quadrat sampling and mobility of animals, considerable quantity of phytal animals must be lost at the underwater working, and real biomass must reach three or four times of this figure. The biomass or density of *Musculus senhousia* attached on *Zostera* much varied and the average value of the data obtained from a few quadrat samples were not reliable. In April, 1961, several species of amphipods and cumaceans (*Pontocrates altamarinus, Stenothoe valida, Ampelisca brevicornis, A. miharaensis, Dimorphostylis asiatica* etc.) were collected at N 4 by a macro-plankton net which accidentally drawn on bottom surface. Small semi-pelagic Crustacea such as *Neomysis japonica* and *Acetes japonica* which were fished for commersial use by Kogai-ami were not evaluated in this survey, too. There must be considerable quantity of small crustaceans on bottom surface other than submerged vegetation, but they were completely ignored by technical limitations.

Discussion

Before the accomplishment of repairment works of River Ohashi-gawa, Lake Shinji-ko was a fresh water lake. After that, capacity of River Ohashi-gawa increased 60% than before and salt water of Lake Naka-umi began to come up to Lake Shinjiko. As the result of that, cultivated land along the lake coast suffered damage by salt.

Miyadi (1932) surveyed benthic animals of Lake Shinji-ko in 1930, at two localities of south coast, off Shinji and off Yumachi. He reported the existence of 9 species of benthic animals; two species of chironomid larvae *Chironomus plumosus* and *Cryptochironomus* sp., two species of worms *Tubifex* sp. and *Tylorrhynchus heterochaetus*, five species of molluscs *Corbicula japonica, Unio dougraciae, Stenothyra* sp. and *Semisulcospira multigranosa*, and an isopod Crustacea *Cyathura* sp.. Among them, brackish mud clam *Corbicula japonica* and Japanese palolo *Tylorrhynchus heterochaetus* were abundant and chironomid larvae were low in density. *Corbicula japonica* distributed in littoral and shallow sublittoral regions, and fauna of profoundal region was composed of *Tylorhynchus heterochaetus*, tubifaecid worms and chironomid larvae. Eleven years after that Ueno (1943) reported much increase of chlorinity of water of the lake (5.43‰ at surface, and 10.06‰ at bottom water of profoundal region), and he reported the disappearance of *Corbicula japonica*, chironomid larvae and tubifaecid worms, and existence of some brackish water components such as *Notomastus* sp., *Cyathura* sp. and *Syncera japonica*, and a marine component *Meretrix meretrix*. All of them distributed less than 2 m in depth, and the deeper region seemed to be sterile. Moreover, densities of animal in shallow zone were very low, only single or a few specimens were collected in 21 trials. These changes of chlorinity of water and bottom fauna were caused by increase of inflow of salt water from Lake Naka-umi and heavy drought which happened at that time. Thereafter, chlorinity of water of Lake Shiji-ko has been varied by the extension works of break-water at the outer end of the Sakai Channel or by the change of water quantity of inflowing rivers. In the present study, many *Corbicula japonica* were found in littoral or sublittoral regions, and considerable chironomid larvae and tubifaecid worms were also found in the profoundal region. Judging from the composition and densities of benthic animals, fauna of the lake seemed to recover the state in 1931. The fauna and regional distribution of benthic animals in Lake Naka-umi were almost equal to those reported by Miyadi et al. (1945). They described two major communities (one of which is *Brachidontes senhousia* (= *Musculus senhousia*) association and the other is *Raeta pulchela—Theora lubrica—Prionospio pinnata* association), and subdivided them into several faciations by subdominant characteristic species. They also reported the disappearance of benthos in south-east region in summer by the lack of oxygen, and survival of pure population of *Prionospio pinnata* in south-west region at that time.

Comparing the composition of macro-benthos of Lake Shinjiko-ko, Lake Naka-umi and Miho Bay, these three waters are almost independent eath other except a few species which are common in neighbouring two waters. Some small crustaceans are common in littoral or shallow sublittoral region of both Lake Naka-umi and Lake Shinji-ko, and some small bivalves such as *Alvenius ojianus*, *Venemolpa micra* are common in inner part of Miho Bay and north region of Lake Naka-umi.

According to the results of the present study, amount of macro-benthic fauna of two brackish waters in spring were similar, however, biomass of benthos in Lake Shinji-ko was larger than in Lake Naka-umi in summer. The lack of dissolved oxygen limited the faunal composition and existence of temporal azoic area in stagnated period much lowered the productivity of benthos in Naka-umi. Considerable quantity of benthic animals which were found in spring suggests high productivity during the circulation period. In the case of Lake Shinji-ko, lack of oxygen is not main limiting factor, but productivity of macrobenthic animals is less than in other eutrophic lakes. In most of fresh water lakes, chironomid larvae are dominant both in number of species and in density or biomass. Paucity of insect larvae in Lake Shinji-ko must be caused by existence of chlorine ion. On the other hand, marine components can not exist for the low chlorinity.

YAMAMOTO (1954) who compared the macro-benthic communities of brackish water lakes in northern Honshu showed a serial change of community patterns accompanying the gradient of chlorinity conditions. He found *Macoma incongrua*—*Brachidontes senhousia* (=*Musculus senhousia*)—*Hydrobia* sp. (=*Fluviocingula nipponica*) community in the inner part of Matsushima Bay, inner part of Lake Obuchi-numa; this is similar to sublittoral community in Naka-umi. Combination of *Paranthura* sp.—*Neosphaeroma oregonensis*—*Corbicula japonica* which was reported from the innermost part of Lake Hachirô-gata resembled the community of littoral or shallow sublittoral region of Lake Shinji-ko. *Chironomus plumosus*—*Tubifex* sp.—*Cryptomya busoensis* community in Lake Takahoko-numa may be comprable to *Chironomus* sp.—*Tubifex* sp. community in the central part of Lake Shinjiko. Lack of *Cryptomya* in Shinji-ko may reflect lower chlorinity of water of the lake. "*Chironomus*—*Tubifex* community" is commonly known from many eutrophic fresh water lakes, but standing crop or productivity of those lakes is much higher than that of Lake Shinji-ko. MIYADI (1932) who compared bottom fauna of several brackish water lakes along the Japan Sea coast concluded that relative importance of chironomid larvae in benthic fauna decreased accompanying with the increase of salinity, and molluscs show inverse trend. In his study Lake Shinji-ko has the highest chlorine ion concentration, and chironomid larvae was the poorest both in number of species and in density.

Summary

Macro-benthic faunas of two brackish lakes, Shinji-ko and Naka-umi, were investigated with Ekman-Birge grab, in each season in 1959, and phytal animals in submerged vegetations were studied in May 1960. According to the composition of benthic animals, Lake Shinji-ko was divided into two regions; *Corbicula japonica* was dominant in littoral and sublittoral regions and profoundal region was occupied by chironomid larvae and tubifaecid worms. Lake Naka-umi was roughly divided into three parts according to the similarity of community composition among the stations. *Musculus senhousia*—*Fluviocingula nipponica* community developed in shallow sublittoral region, *Raeta pulchela*—*Theora lubrica*—*Prionospio pinnata* community developed in south-east part

of the lake where dissolved oxygen much decreased in summer. North-west region was characterized by existence of *Anadara subcrenata*, *Paphia undulata*, several tunicates and sea pens. These regional distribution of communities corresponds to the difference of physical environmental conditions especially chlorinity and dissolved oxygen concentration. Seasonal change of those benthic communities were described and rough estimation of total standing crop of macro-benthos was carried out.

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Appendix Table 1. Environmental conditions of the bottom at the sampling stations in Lake Naka-umi.

Apr. 27th, 1959

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Depth (m)	5.3	5.6	6.7	6.5	3.8	5.8	6.2	5.4	7.0	6.7	1.95	7.6	0.9	6.8	5.0	2.0	3.0	5.1
Substratum	fS. M	M	fS. M	S	fS. M	M	M	M. Silt	M. Silt	M	S	M. Silt	S	fS. M	fS	S	M	M
Chlorinity (‰)	13.46	14.50	16.58	17.08	9.25	12.12	14.95	14.23	16.44	8.86	9.64	9.45	9.27	12.26	9.49	9.45	9.54	18.18
Dissolved O_2 (cc/l)	6.01	5.94	5.69	5.95	6.40	6.41	5.95	5.08	2.17	6.36	7.36	6.38	—	5.92	6.35	6.15	6.53	6.25
Saturation % of dissolved O_2	99	99	96	101	102	104	99	84	37	100	119	100	—	97	97	100	106	107
pH	8.3	8.2	8.1	8.3	8.2	8.2	8.2	8.2	8.1	8.1	—	8.3	—	8.2	8.2	8.2	8.3	8.4
Water temp. (°C)	16.64	16.53	16.08	16.02	17.49	16.64	16.33	16.46	16.10	16.14	17.72	16.98	17.68	16.94	16.28	17.64	18.02	15.55
Mud temp. (°C)	16.7	16.5	16.3	16.5	17.2	16.4	16.5	16.8	16.0	16.3	17.3	15.8	17.3	16.3	16.3	17.5	16.9	16.7
Air temp. (°C)	16.6	16.1	16.6	16.0	16.7	16.7	17.2	16.4	17.2	17.5	16.1	16.2	16.9	17.8	17.7	16.9	17.4	16.8

July 31st, 1959

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Depth (m)	5.4	5.5	6.3	6.8	3.5	5.8	6.3	5.5	6.5	5.8	2.0	7.7	—	7.1	—	1.5	3.3	6.0
Substratum	mS	M	M	Sh. S	M. fS	M	M	M	M	M. Silt	S	M		M		S	M. Silt	S
Smell of H_2S								+	+	+		+		+			+	
Chlorinity (‰)	15.82	16.39	17.26	16.45	11.21	16.98	16.12	15.47	15.94	15.10	7.90	15.98		15.80		7.33	10.67	17.08
Dissolved O_2 (cc/l)	3.45	2.54	3.69	4.49	4.60	1.64	1.89	0.00	0.39	0.24	5.98	0.00		0.00		5.27	2.22	4.31
Saturation % of dissolved O_2	71	52	74	92	93	33	38	0	8	5	115	0		0		102	44	88
pH	8.2	8.1	8.2	8.25	8.1	7.9	7.9	7.8	7.7	7.75	8.4	7.7		7.8		8.3	7.8	8.15
Water temp. (°C)	27.83	26.77	26.80	27.41	28.88	26.53	26.85	24.23	25.42	25.81	29.55	23.40		23.88		29.82	28.60	27.20
Mud temp. (°C)	27.2	26.5	26.0	—	28.2	27.0	26.2	25.0	23.7	24.5	29.6	23.0		24.4		29.5	27.6	27.3
Air temp. (°C)	28.2	28.8	28.5	28.7	31.7	30.4	30.9	2.98	29.9	30.3	29.4	29.4		30.2		30.4	30.7	29.3

Oct. 21st, 1959

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Depth (m)	6.1	6.3	6.5	5.9	3.5	6.1	6.6	6.3	7.0	6.5	1.05	8.0	—	7.0	—	2.0	3.5	7.8
Substratum	M	M	M	Sh. cS	M	M	M	M. Silt	M	M. Silt	S	M. Silt		M. Silt		M	M. Silt	Sh. cS
Smell of H_2S								+	+	+		+		+			+	
Chlorinity (‰)	14.40	15.83	15.13	13.83	7.42	10.57	14.40	15.85	14.97	14.35	6.27	16.18		15.65		8.27	9.55	17.88
Dissolved O_2 (cc/l)	1.51	3.13	0.66	1.36	6.05	3.63	0.36	0.00	0.57	0.41	6.97	3.68		0.24		6.38	6.11	4.70
Saturation % of dissolved O_2	27	57	12	—	91	62	7	0	10	7	109	69		4		102	100	87
pH	7.8	7.9	7.8	7.8	8.0	7.75	7.8	7.9	7.7	7.7	8.3	7.8		7.8		8.2	7.9	8.2
Water temp. (°C)	21.40	21.10	21.89	—	18.08	19.90	21.60	22.80	22.12	21.48	18.07	22.42		22.37		18.09	18.78	20.75
Mud temp. (°C)	21.5	21.9	21.8	20.8	19.5	21.5	20.5	22.3	22.3	22.0	18.6	22.6		21.2		19.0	19.8	—
Air temp. (°C)	18.6	19.7	19.4	19.8	26.5	18.5	20.0	19.1	20.0	19.5	20.0	20.0		20.0		20.1	20.0	21.2

Jan. 20th, 1960

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Depth (m)	5.5	5.7	6.2	7.0	3.5	5.6	6.2	6.1	6.9	6.3	2.05	7.9	—	6.8	—	2.0	2.95	5.7
Substratum	M	M	M	Sh. S	M	M	M	M. Silt	M	M. Silt	S	M. Silt		M. Silt		S	M. Silt	Sh. cS
Chlorinity (‰)	14.69	12.85	16.83	15.57	5.84	14.29	14.94	14.33	15.58	14.43	6.99	15.08		14.96		7.63	10.33	17.69
Dissolved O_2 (cc/l)	8.20	6.16	5.11	5.09	5.59	3.96	4.15	4.69	4.79	3.04	8.34	2.21		2.29		8.12	5.25	6.46
Saturation % of dissolved O_2	122	87	79	77	69	59	63	69	74	46	105	34		35		103	70	100
pH	8.2	8.2	8.2	8.1	8.0	8.0	8.1	—	8.1	8.0	8.1	8.0		8.0		8.1	8.1	8.3
Water temp. (°C)	10.48	9.40	11.13	10.83	6.64	10.80	11.00	11.11	11.70	11.52	6.70	12.50		11.95		7.00	8.32	11.12
Mud temp. (°C)	12.4	13.0	12.0	—	8.1	12.0	12.0	13.0	12.1	12.5	8.2	13.4		12.7		8.9	9.3	—
Air temp. (°C)	8.1	8.2	8.2	6.9	8.1	8.4	8.2	8.1	9.7	7.9	8.4	9.7		8.7		8.7	8.0	1.6

Appendix Table 2. Density and standing crop of animals in Lake Naka-umi. Upper figure of each column shows density (N/m^2) and lower figure shows biomass ($gr./m^2$).

April 27th, 1959

Station	8	10	12	14	9	7	6	3	1	2	4	17	5	11	13	16	18
Raeta pulchela	—	37.5 (75.0)	362.5 (137.5)	562.5 (233.75)	300 (72.5)	183.3 (68.3)	12.5 (1.25)	100 (35.0)	37.5 (10.0)	—	—	—	—	—	—	—	—
Theora lubrica	—	112.5 (3.75)	375 (23.75)	162.5 (3.75)	375 (21.25)	150 (6.67)	162.5 (3.13)	137.5 (11.25)	225.0 (16.25)	175 (15.0)	—	—	—	—	—	—	—
Anadara subcrenata	—	—	—	—	25 (58.75)	—	12.5 (27.5)	—	25 (25.0)	—	100 (160.0)	—	37.5 (87.5)	—	—	—	—
Musculus senhousia	100 (6.25)	25 (2.5)	12.5 (1.2)	12.5 (1.2)	550 (18.75)	600 (20.0)	450 (32.5)	—	175 (5.0)	—	—	300 (10.0)	2237.5 (195.0)	28650 (465.0)	22300 (236.25)	23160 (268.75)	4525 (191.25)
Fluviocingula nipponica	—	—	—	—	—	—	—	—	—	—	—	50 (0.10)	625 (5.0)	2875 (27.5)	112.5 (8.75)	1187.5 (6.25)	—
Stenothyra edogawaensis	—	—	—	—	—	—	25 (0.32)	—	—	12.5 (0.16)	—	—	100 (1.25)	137.5 (2.5)	187.5 (6.0)	12.5 (0.15)	—
Other molluscs	—	—	—	—	—	—	75.0 (1.25)	100 (33.75)	—	12.5 (+)	—	—	75 (3.75)	62.5 (1.25)	225 (6.25)	187.5 (3.75)	—
Prionospio pinnata	—	—	150.0 (2.5)	300 (5.0)	512.5 (16.25)	633.3 (15.0)	262.5 (3.75)	162.5 (5.0)	175 (6.25)	162.5 (5.0)	—	—	—	—	—	—	—
Other polychetes	—	—	—	—	—	—	—	112.5 (7.5)	25 (+)	12.5 (+)	12.5 (+)	—	12.5 (+)	125 (2.5)	125 (1.0)	137.5 (2.50)	62.5 (+)
Tunicates	—	—	—	—	—	—	100 (148.75)	50 (136.5)	—	125 (261.25)	—	—	—	—	—	—	—
Crustaceans	—	—	—	—	—	—	—	—	—	—	—	—	—	375 (3.75)	362.5 (3.50)	82.5 (5.0)	—
Total biomass	6.25	81.25	164.85	243.7	187.5	109.97	218.45	229.0	62.5	281.4	160.0	10.1	292.5	502.5	261.75	286.4	191.25
Number of sp.	1	3	4	4	5	4	9	11	9	8	4	2	6	11	12	9	5

July 31st, 1959

Station	8	10	12	14	9	7	6	3	1	2	4	17	5	11	13*	16	18
Raeta pulchela	—	—	—	—	—	—	—	—	—	—	—	—	—	—		—	—
Theora lubrica	—	—	—	—	—	—	—	—	—	—	—	—	—	—		—	—
Anadara subcrenata	—	—	—	—	—	—	—	25 (46.25)	—	—	212.5 (543.75)	—	—	—		—	—
Murculus senhousia	—	—	—	—	—	—	—	—	—	—	—	—	6637.5 (745.0)	1162.5 (37.5)		3132.5 (870.5)	312.5 (86.25)
Fluviocingula nipponica	—	—	—	—	—	—	—	—	—	—	—	—	3012.5 (13.75)	6125 (21.25)		4525 (8.75)	37.5 (2.5)
Stenothyra edogawaensis	—	—	—	—	—	—	—	—	—	—	—	—	662.5 (2.5)	—		12.5 (+)	—
Other molluscs	—	—	—	—	—	—	—	—	—	—	—	—	225 (43.75)	—		50 (3.75)	—
Prionospio pinnata	—	—	—	—	142.5 (5.0)	462.5 (15.0)	300 (8.75)	25 (0.75)	50 (1.55)	350 (10.0)	—	—	—	—		—	—
Other polychaetes	—	—	—	—	—	—	—	50 (+)	—	—	—	—	125 (3.75)	—		12.5 (+)	125 (1.88)
Tunicates	—	—	—	—	—	—	—	—	—	—	—	—	—	—		—	—
Crustaceans	—	—	—	—	—	—	—	—	—	—	—	—	—	—		13.75 (2.5)	12.5 (+)
Total biomass	0	0	0	0	5.0	15.0	8.75	47.0	11.55	10.0	543.45	0	808.75	58.75		885.5	90.63
Number of sp.	0	0	0	0	1	1	1	2	1	1	1	0	8	3		9	6

Oct. 21st, 1959

Station	8	10	12	14	9	7	6	3	1	2	4	17	5	11	31	16	18
Raeta pulchela	—	—	—	—	—	—	—	—	—	—	—	—	—	—		—	—
Theora lubrica	—	—	—	—	—	—	—	—	—	—	—	—	—	—		—	—
Anadara subcrenata	—	—	—	—	—	—	—	—	—	—	25 (90.0)	—	—	—		—	—
Musculus senhousia	—	—	—	—	—	—	—	—	—	—	—	—	—	ca. 4500 (217.5)		—	—
Fluviocingula nipponica	—	—	—	—	—	—	—	—	—	—	—	—	—	4375 (30.0)		1062.5 (7.5)	—
Stenothyra edogawaensis	—	—	—	—	—	62.5 (1.0)	87.5 (1.3)	75 (0.96)	37.5 (0.46)	125 (1.85)	—	—	75 (0.95)	—		100 (1.20)	—
Other molluscs	—	—	—	—	—	—	—	—	—	25 (0.5)	—	—	—	—		—	—
Prionospio pinnata	—	—	—	—	—	37.5 (+)	37.5 (+)	12.5 (+)	12.5 (+)	25 (+)	—	—	—	—		—	—
Other polychaetes	—	—	—	—	—	—	—	—	—	—	12.5 (+)	—	12.5 (+)	300 (1.25)		—	—
Crustaceans	—	—	—	—	—	—	—	—	—	—	—	—	—	—		—	12.5 (+)
Total biomass	0	0	0	0	0	1.0+	1.3+	0.96+	0.46+	1.85+	90.0+	0	0.95+	248.75		8.7	+
Number of sp.	0	0	0	0	0	2	2	2	2	3	2	0	2	3		2	1

Jan. 20th, 1960

Station	8	10	12	14	9	7	6	3	1	2	4	17	5	11	13	16	18
Raeta pulchela	—	50 (1.25)	—	—	50 (1.88)	—	—	—	—	—	—	—	—	—		—	—
Theora lubrica	—	—	—	—	—	—	—	—	—	—	—	—	—	—		—	—
Anadara subcrenata	—	—	—	—	—	—	—	25 (188.75)	—	50 (371.88)	—	—	37.5 (5.0)	—		—	—
Musculus senhousia	—	—	—	—	—	—	—	—	—	—	—	—	—	5025 (48.25)		3515.6 (33.75)	116.25 (6.75)
Fluviocingula nipponica	—	—	—	—	—	—	—	—	—	—	—	—	500 (3.12)	—		—	—
Stenothyra edogawaensis	—	—	—	—	—	600 (2.5)	312.5 (1.25)	12.5 (+)	12.5 (+)	550 (2.5)	—	—	—	—		—	—
Other molluscs	—	—	—	—	—	—	—	487.5 (3.75)	150 (1.25)	200 (3.12)	—	—	12.5 (+)	50 (2.5)		—	—
Prionospio pinnata	—	125 (1.88)	—	100 (1.85)	425 (7.5)	575 (11.88)	687.5 (12.5)	—	62.5 (2.5)	87.25 (2.5)	—	—	—	—		—	—
Other polychaetes	—	—	—	—	—	—	—	75.5 (3.75)	75 (2.5)	—	37.5 (1.25)	12.5 (+)	—	100 (1.88)		237.5 (6.25)	12.5 (+)
Tunicates and sea pens	—	—	—	—	—	—	—	112.5 (49.4)	25 (0.6)	50 (3.12)	—	—	—	—		—	—
Crustaceans	—	—	—	—	—	—	—	12.5 (+)	—	—	—	—	—	112.5 (2.5)		—	—
Total biomass	0	3.13	0	1.85	12.5	14.38	13.75	245.65	333.17	9.37	6.25	+	8.12	55.13		40.0	6.75+
Number of sp.	0	2	0	1	2	2	2	9	6	6	2	1	3	7		6	3