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Distribution of Benthos in Relation to the Sulfide-Content in the Bottom Sediments of Mixo-Polyhaline Lake Notoro, Hokkaido

Shigeru NAKAO*

Abstract

Changes are described in the macrobenthic fauna in Lake Notoro in response to the enrichment of dissolved oxygen of bottom water and the diminution of total sulfide content in the bottom sediments, brought about by quantities of the inflow from outer sea water through an artificially constructed mouth.

The dredging and enlarging of the outlet resulted in a better aeration of deeper water at all seasons and a wider distribution of benthic animals. The total sulfide content in the bottom sediments where no benthos had been found before this artificial construction decreased rapidly. In deeper water of the better aeration the benthic community, though showed low diversity value, was newly found in the bottom with such high content as 4.27 ‰ in total sulfide and the index values of benthic communities increased with the decreasing in total sulfide content and showed a rapid rate of increase in total sulfide amount smaller than 1 ‰.

Marine habitats with hydrogen sulfide offer few possibilities of existence for marine animals. Especially poorly aerated bottom sediments are rich in sulfide and H_2S. The knowledge on the degree of resistance to hydrogen sulfide is, however, not sufficient for assessing the capacities of marine bottom invertebrates to survive in such habitats. The resistance of various communities of benthos on the Black Sea coast to hydrogen sulfide was investigated by Jacubowa and Malm[1]. Polychaetes and bivalves of a mud community were more resistant than species of a mussel-bank community. Theede et al.[2] have reported that under laboratory condition, marine bottom invertebrates showed a pronounced differences in resistance to O_2-deficiency and the presence of H_2S. These differences were parallel to the different substrates on, or, in which the species naturally occurred. Yoshimura and Wada[3] have observed in Lake Hamanako that the critical concentration of sulfide content in the bottom sediments for benthos was 1 ‰. A sudden occurrence of hydrogen sulfide can cause mass mortalities in the local fauna. Along the south-west coast of Africa, a large amount of hydrogen sulfide was formed in the bottom sediments, and crustanceans, molluscs and other invertebrates were destroyed as a result[4]. An amount of hydrogen sulfide larger than 1 ‰ in the bottom sediments in Lake Hamanako could cause mass mortalities of oyster[5].

We observed the response of benthos communities to hydrogen sulfide content in the bottom sediments in Lake Notoro, Hokkaido. The first results of this observation with special reference to the appearance of benthic fauna in the azoic zone are presented in the present paper.

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Methods

Quarterly bottom samples were taken using a 1/17 m^2 grab sampler modified by Tamura[6] from winter to fall of 1972, and summers of 1975 and 1977. Five replicate samplings were made at all stations. The contents were washed through a sieve of 1.0 mm mesh. The animals retained on the sieve were fixed in 10 % formalin solution, identified into species, and counted. The counts were adjusted to number per m^2.

Sediment samples were analysed for organic content by a MT 500 type Yanaco C-N corder and for total sulfide content by the semi-micro method as described by Tomiyama and Kanzaki.[7] The dissolved oxygen content of the water was determined by Winkler's method and chlorinity determined by Fajan's method.

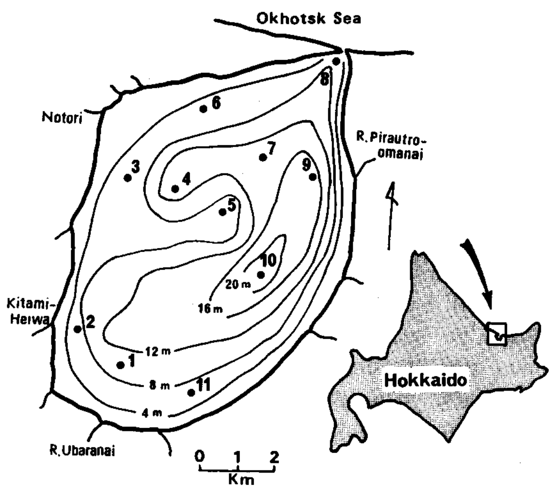

Fig. 1. Map of Lake Notoro showing the sampling stations. The lines indicate the approximate depth in meters.

Results

Characterization of the sample area

Formerly the outlet of the lake had become narrower and shallower from the latter part of fall to early spring by the accumulation of sand, and during these four months both the outflow of the lake water and inflow from the outer Okhotsk Sea water had been stopped. In April 1974, the outlet was artificially constructed by dredging and was thus enlarged. Hence the amount of both inflow and outflow through the artificially constructed mouth increased distinctly not only in the colder seasons but also in the other seasons. Before this artificial construction Lake Notoro exhibited seasonal variation in vertical temperature, chlorinity and dissolved oxygen gradients (Fig. 2). Station 1 was situated on the inner part with a depth of approximately 12 m, and Station 9 on the east middle part with 20 m

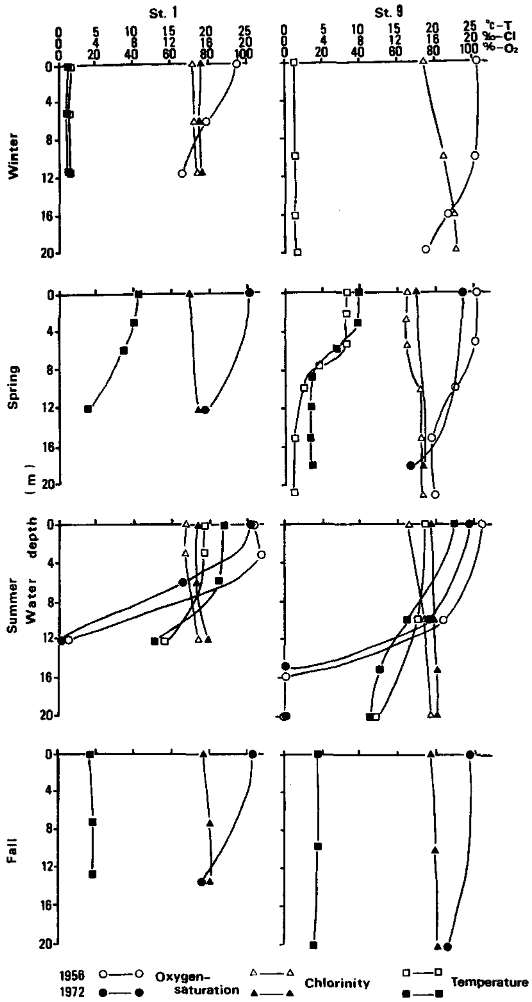

Fig. 2. Profiles showing the seasonal changes of oxygen saturity (%), chlorinity (‰) and water temperature (°C) at two sampling stations. Profiles in 1956 are introduced from the data by Kuroda et al.[23]. Water temperatures in the winter show the degrees below freezing point.

depth (Fig. 1). In the winter (February 1972), vertical water temperature in the sample stations distributed isothermally showing −1 °C from surface to bottom.

Weak chlorinity gradients occurred and oxygen saturation decreased slightly toward the bottom. In the spring (May 1972), stronger water temperature gradients occurred at these stations and the temperature decreased from surface to bottom.

Vertical distribution of chlorinity and oxygen saturation were similar to those in the winter. During the summer (August), a definite thermocline developed and was stabilized in part by the presence of a halocline. The oxygen saturation decreased remarkably in the layer deeper than 10 m. Especially at Station 9, a

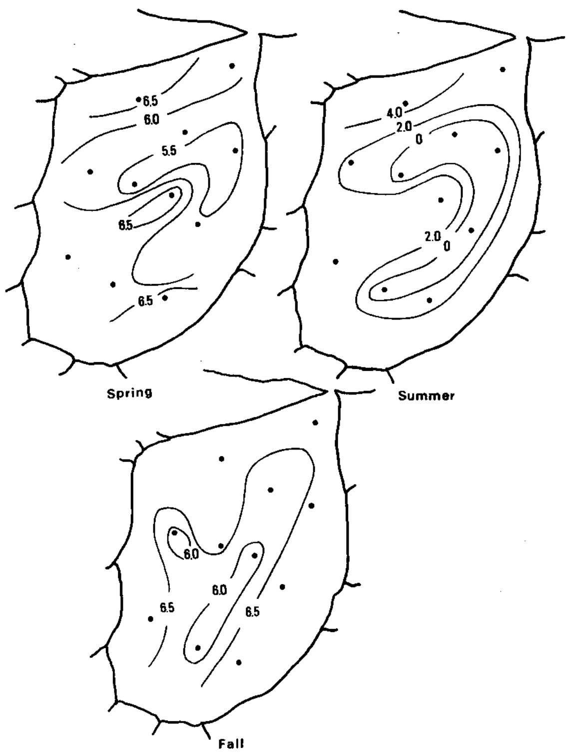

Fig. 3. Horizontal distribution of dissolved oxygen content (cc/L) in bottom water in 1972 before the mouth was artificially constructed in Lake Notoro.

complete lack of dissolved oxygen occurred in the layer deeper than 15 m. In the fall (October), these general trends were similar to those in the winter except water temperature. As described above, when the water column became stratified during the summer months, low dissolved oxygen condition developed in bottom waters at the layer deeper than 10 m. Figure 3 indicates the horizontal distribution of dissolved oxygen content in the bottom water. It shows a decreasing dissolved oxygen with increasing depth in each season. Low dissolved oxygen concentrations were observed only during the summer and were confined to the layer deeper than about 10 m, a complete lack of oxygen occurred in the layer deeper than approximately 15 m. In the other seasons these tendencies disappeared, and high dissolved oxygen conditions developed in the whole area except the middle part where a little low oxygen in the spring could be noticeable.

After April 1974 when the mouth of the lake had been artificially constructed, the amount of the inflow from the outer Okhotsk Sea water and the outflow of the lake water increased decidedly all the year round. This topographic change would naturally affect the quality of the lake water. A thermocline and low dissolved oxygen concentration as occurred during the summer of 1972 were not afterward observed (Fig. 4). When the water column was not stratified, it was well

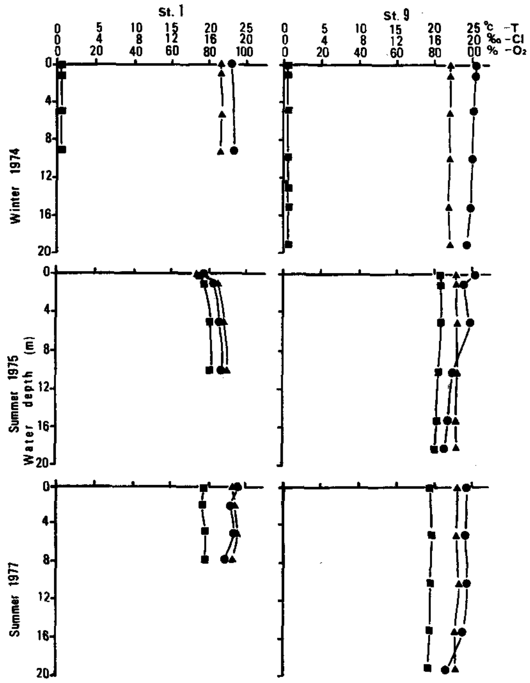

Fig. 4. Profiles showing the seasonal changes of oxygen saturity (%), chlorinity (‰) and water temperature (°C) at two stations after the mouth was artificially constructed in Lake Notoro.

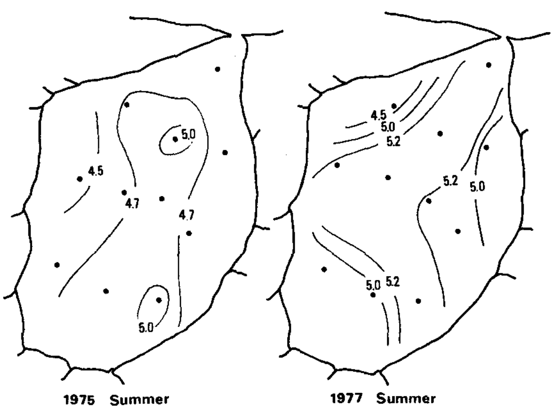

Fig. 5. Horizontal distribution of dissolved oxygen (cc/L) in bottom water in the summers of 1975 and 1977.

oxygenated from surface to bottom (Fig. 4).

From the facts described above, we may conclude that the difference in vertical chlorinity, water temperature and dissolved oxygen could be scarcely recognized

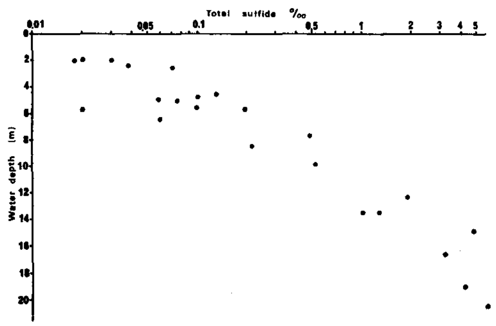

Fig. 6. Relation between depth (m) and total sulfide content (‰) in the sediments in August 1972 and 1973.

between surface and bottom, after April 1974, but the chlorinity during summer was 1 ‰ higher than that of winter. Horizontal oxygen content in the bottom layer during summers 1975 and 1977 are given in Figure 5. As understood from the Figure, oxygen content increased distinctly as compared with that of summer of 1972. The lowest oxygen content was 4.33 cc/l at Station 3 in 1975. Horizontal oxygen gradients did not vary in intensity with station and year.

Substrate characteristics vary with depth[8)9)10)]. In depths between 0 and 10 m, sediments were commonly sorted as fine or coarse sand, while beyond 15 m they were commonly or well sorted as very fine sand. The sediments between 10 m and 15 m were ill sorted sand. Figure 6 shows the relation between depth

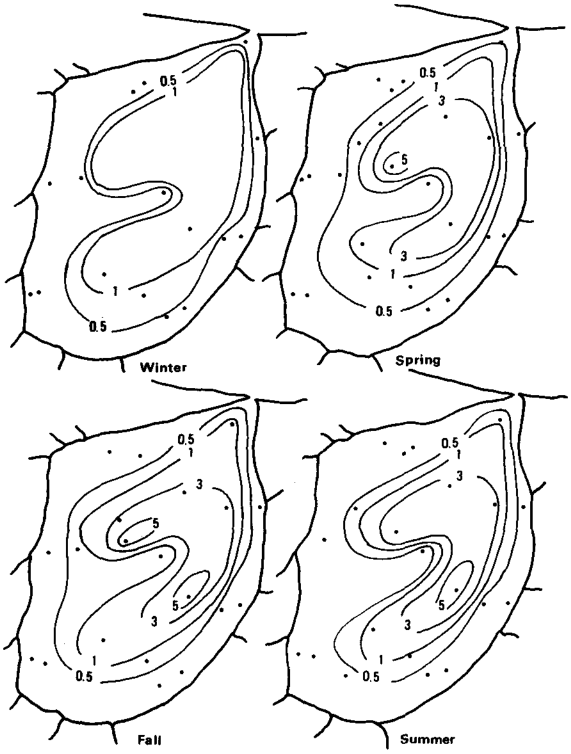

Fig. 7. Distribution of total sulfide content (‰) in the bottom sediments in 1972 before the mouth was artificially constructed. Results are stated as per mills of dry weight.

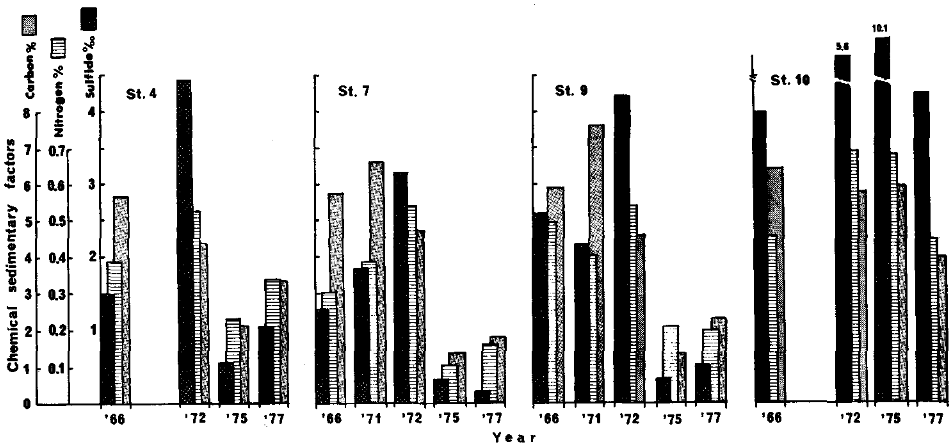

Fig. 8. Variation in the values of various chemical contents in the bottom sediments at each station.

and total sulfide content in the sediments. Total sulfide contents increased gradually with increasing depths at stations less than 10 m depth, and showed a rapid rate of increase at stations greater than 15 m depth. Values of total sulfide were below 1 ‰ at the former stations and ranged between 3.2 ‰ and 5.6 ‰ at the latter. The distribution of total sulfide content in the sediments of the surveyed area, as shown in Figure 7, was similar to the distribution of water depths at all seasons.

The lowest values corresponded to the shallowest area (<0.5 ‰) and the middle part with more than 15 m depth showed the highest concentration (>3 ‰). The rest of the sediments had intermediate values. We were not able to identify any seasonal trends in the distribution of values of total sulfide, but the values decreased abruptly after 1975. Low contours developed in the middle part except around Station 10. At a depth of greater than 15 m was found less than 1‰ in total sulfide content. Now, yearly trends of the distribution of total sulfide content at four stations with greater depth are shown in Figure 8. Total sulfide content in 1975 indicated an obvious decrease at Stations 4, 7 and 9, and remained almost unchanged thereafter. On the other hand, at Station 10 in 1975 the value of total sulfide increased by about two times that of 1972 and was followed by a relative recovery in 1977. These yearly trends in the distribution of total sulfide content were also noticeable in that of organic matter content in the sediments at four stations.

Benthos communities

The total number of species in the area surveyed in 1972 is shown in Figure 9.

At each station those species did not vary so much seasonally. Only Station 1 in the summer showed a smaller number than those of the other seasons. The large total number of species occurred consistently in the habitat less than 10 m in depth except Station 3 with a small total number.

Throughout all seasons, benthos were not observed in the habitats greater than

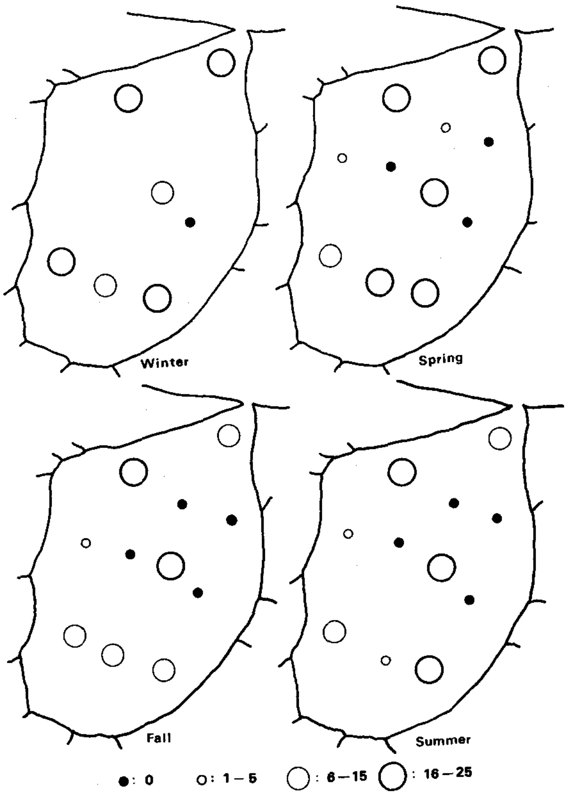

Fig. 9. Seasonal distribution of number of species of benthic animals obtained in 1972 before the mouth was artificially constructed in Lake Notoro.

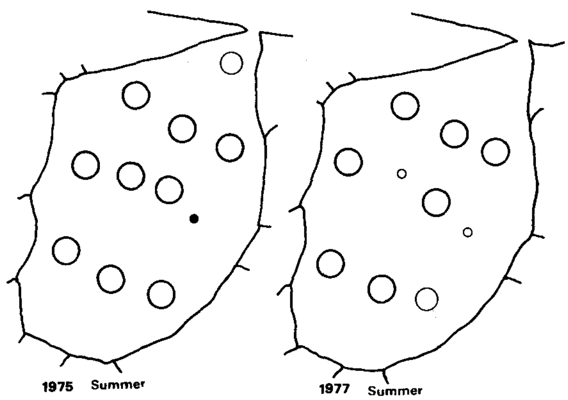

Fig. 10. Distribution of number of species of benthic animals obtained in the summers of 1975 and 1977 after the mouth was artificially constructed. Symbols as in Fig. 9.

Table 1. *Species name of benthic animals with numbers of individuals found in one square meter of the substratum at Stations 4, 7, 9 and 10 during the summer sampling period of each year.*

Species name	Sept. 1975				Sept. 1977			
	St. 4	St. 7	St. 9	St. 10	St. 4	St. 7	St. 9	St. 10
Mitrella tenuis	-	3	-	-	6	1688	11	-
Musculus senhousia	31	85	119	-	23	170	136	-
Mya arenaria oonogai	-	-	-	-	6	-	-	-
Harmothoe imbricata	7	-	3	-	-	22	-	-
Anaitides maculata	-	7	44	-	-	-	-	-
Eteone longa	14	3	17	-	-	-	11	-
Sigambra tentaculata	10	-	-	-	-	5	17	119
Nereis zonata	3	-	-	-	-	-	-	-
Nephtys caeca	-	-	-	-	-	-	5	-
Glycinde sp.	61	31	27	-	-	34	62	-
Nothria sp.	3	3	-	-	-	-	-	-
Lumbrineris sp.	-	31	-	-	-	130	5	-
Dorvillea japonica	459	10	7	-	527	153	209	10237
Scoloplos armiger	7	10	3	-	-	-	-	-
Laonice cirrata	10	3	3	-	-	-	-	-
Prionospio malmgreni	116	88	34	-	-	357	436	-
Spio sp.	-	-	-	-	-	5	-	-
Spiophanes bombyx	-	-	-	-	-	-	22	-
Pseudopolydora kempi japonica	3	17	17	-	-	5	-	-
Cirratulus cirratus	-	-	-	-	-	39	5	-
Pherusa plumosa	3	-	-	-	-	-	10	-
Scalibregma inflatum	717	150	150	-	-	-	17	-
Ophelia limacina	-	3	-	-	-	-	-	-
Heteromastus giganteus	-	-	-	-	-	85	34	-
Owenia fusiformis	10	10	7	-	-	-	-	-
Cistenides soldatovi	-	-	3	-	-	102	-	-
Pista sp.	-	-	-	-	-	-	10	-
Ampharete arctica	-	-	3	-	-	-	-	-
Mellinna elisabathae	20	17	3	-	-	10	17	-
Pseudosabellides littoralis	7	3	-	-	6	5	5	-
Chone sp.	-	17	10	-	-	-	-	-
Cumacea	-	-	3	-	-	-	-	-
Pseudochironomus sp. A	-	7	-	-	-	-	-	-
Paranthura sp.	-	-	-	-	-	5	-	-
Caprellidea	-	-	-	-	-	62	28	-
Amphioplus ancistrouts	3	-	-	-	-	158	5	-
Nemertinea	17	17	7	-	-	39	56	51

15 m in depth and with a large amount of total sulfide content in the sediments. In 1975 the total number of species occurring in the lake showed more abundance except a comparatively small azoic zone around Station 10, but in 1977 only a few species occurred at Station 10 (Fig. 10). Consequently the azoic zone continuously observed in the area with the greater depth in 1972 seemed to have disappeared in 1977 completely. The species occurring at four stations at greater depth in 1975 and 1977 are presented in Table 1. The total number of species occurring at Stations 7 and 9 did not vary much yearly. However, the component in the

numerically dominant species changed to some extent between 1975 and 1977. The values of Station 4 decreased remarkably in 1977, and at Stations 4 and 10 where a little number of species occurred in 1977, only a single species *Dorvillea japonica* predominated.

Diveristy indices

Comparisons of faunal variation from year to year are facilitated by considering biological indices designed to demonstrate the degree of similarity or diversity between different samples. In recent years many indices have been proposed and used in the comparison of fauna from a wide range of habitats; each index has inevitably some disadvantages, either mathematical or descriptive, arising from the necessity of compressing a considerable range of information into a single index[11]. For the purpose of the present survey it was decided to calculate two of the indices which have been relatively widely used. 1) Diversity measured by Sanders' rarefaction method.[12] This graphical method reduces the samples compared to a common size, estimated species numbers are generated for each sample size, and the resultant species abundance curves so constructed are compared. 2) Index of species diversity measured by MacArthur' information function[13] $H'=-\sum_{i}^{S}P_1 \log_2 P_1$, where S is the total number of species and P_1 is the observed proportion of individuals belonging to the i^{th} species (i=1, 2 .. S).

Rarefaction lines generated from data for each year at Stations 4, 6, 7, 9 and 10 are given in Figure 11. At Station 6 the years from 1972 to 1977 all fall within a narrow band, i.e. the high diversity values for these years are essentially similar.

At Station 7 in 1975, the diversity is similar to that of Station 6, but in 1977 the line declines toward the x-axis. The number of species was almost unchanged between 1975 and 1977, but high individual numbers of a single species were found at this station in 1977. At Station 9 in 1975 and 1977 and Station 4 in 1975

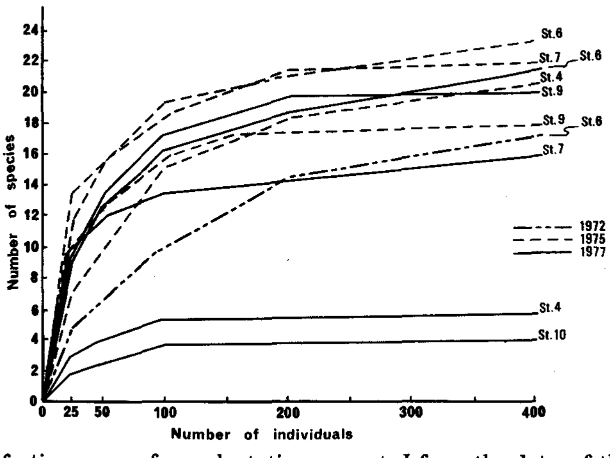

Fig. 11. Rarefaction curves for each station generated from the data of the survey, up to population sizes of 400 individuals.

Table 2. *Values of the information statistic H′.*

Station	1975	1977
4	2.30	0.56
7	3.34	2.50
9	3.14	2.92
10	-	0.24

rarefaction lines fall within a narrow band, and the diversity values are essentially similar to those of Station 6. At Stations 4 and 10, in 1977, the lines decline remarkably towards the x-axis. Very small numbers of species but large individual numbers were found at these stations in 1977. Particularly in Station 10, in 1977, the lowest values were found. Values for H′ that have been calculated for samples obtained from the survey of each year at five stations are given in Table 2. There is little difference among the yearly values at Stations 6 and 9 respectively, but Station 7 shows a slight decline in the index value. At Station 4 the index fell fairly sharply in 1977.

Discussion

Formerly both chlorinity and temperature between surface and bottom in Lake Notoro showed considerable differences in the warmer season respectively, and accordingly these differences resulted in having caused stagnation of the bottom water. In the summer before the artificial construction of the mouth in 1974, a complete lack of oxygen in bottom water might be caused not only by an excessively small exchange of water but also by the destruction of a large amount of organic matter in the sediments. In sea-water poor in oxygen, hydrogen sulfide is formed via reduction of sulphate[3)5)]. For many animals, lack of oxygen or presence of hydrogen sulfide proves fatal. Marine regions poor in oxygen are, therefore, characterised by the presence of a strikingly few species[14)15)]. In the bottom of the Gotland-Deep, deficient in oxygen, only *Scoloplos armiger* in the mud, and *Pontoporia femorata* and *Terebellides strömii* on loomy bottoms, were found[16)]. While in bottom water where no oxygen is contained except in the warmer season and rich in the other seasons, benthic animals were found on bottoms except during the oxygen lacking period[17)], and Moore[18)] found living nematodes in oxygen destitute bottom layers of the Clyde Sea. From the facts of survival of a nematode and an oligochaete species in anaerobic benthal of Lake Tiverias, Por and Masry[19)] suggested that highly adapted anaerobic populations might live also in other subtropical lakes. However, in bottoms with depth greater than 15 m in Lake Notoro where dissolved oxygen in bottom layers were anaerboic only in the summer but aerobic in other all seasons, no benthic animals were found throughout the year. The main origin of this azoic zone existing in Lake Notoro was caused with oxygen defininciency in the summer and a large amount of total sulfide in the sediments at all seasons.

The relations between diversity H′ and total sulfide content are shown in Figure 12. Before 1974 when the mouth was artificially constructed, no benthic animals had been found at all in bottoms with an amount of total sulfide larger than 1‰

in the sediments. After 1975 when the dissolved oxygen of bottom water was favourable, 0.24 and 0.56 of diversity values were perceived in the bottom with 4.24 and 1.27‰ of total sulfide respectively in the sediments. While in bottoms with total sulfide smaller than 1‰, index values increased sharply.

According to Yoshimura and Wada[3] in Lake Hamanako, no benthic animals were found in bottoms with total sulfide larger than 1‰ in the sediments, irrespective of oxygen content. After 1975 when the dissolved oxygen of bottom water changed for the better in Lake Notoro, however, the benthic community, though showing a low diversity value of 0.24, was newly found in the bottom with such high content as 4.27‰ in total sulfide. Furthermore a benthic community with 0.56 in diversity value was observed in the bottom with 1.27‰ in total sulfide content. While in the bottoms with total sulfide amount smaller than 1‰, index values of benthic communities increased sharply (Fig. 12.)

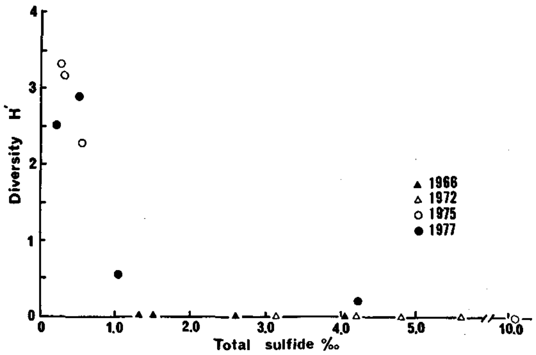

Fig. 12. Relation between diversity values and total sulfide content in the sediments at four stations.

The present findings in Lake Notoro that supply arguments for those diversity indices provide one of the best ways to detect and evaluate pollution as pointed out by Wilhm[20] and Wilhm and Dorris[21].

Table 3. *Yearly changes of fisheries catch in Lake Notoro during these ten years. (ton). The data are quoted from Fisheries Statstics in 1974, and 1976, Abashiri City.*

Year	Flat fishes	Herring	"Komai"	Half beak	Gray mullet	"Chika" surfsmelt	Scallop	Oyster	Sea urchin	Welks	Others	Total
1967	42	147	12	1	0.7	2	13	4	-	10	24	256
1968	19	58	29	0.4	-	0.4	-	3	-	12	-	122
1969	32	134	14	16	7	2	-	-	-	0.6	20	225
1970	13	144	22	0.3	3	2	-	-	-	10	7	202
1971	17	135	30	7	1	9	33	-	-	10	5	247
1972	4	114	52	0.3	0.01	7	57	-	-	5	11	250
1973	37	21	3	1	3	4	85	-	-	2	12	168
1974	70	317	1	2	-	2	75	-	6	0.5	-	473
1975	61	82	10	-	-	24	116	-	31	0.3	178.8	503
1976	85	26	-	-	-	158	113	-	10	-	35	427

Miyadi and Habe[22] reported that in the Yosanaikai on the southwestern coast of the Japan Sea, the dredging of the outlet resulted in a better aeration of deeper water, a wider distribution of benthic animals and a larger catch of sardin, other fishes and useful molluscs. A similar fact was found in Lake Notoro where after 1974 catches of flat fishes, "Chika" surfsmelt, scallop, sea urchin and others showed a rapid increase, thus making the total catch attain about two times that of the former years, as given in Table 3.

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