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PROJECT FOR MONITORING THE ENVIRONMENT OF COASTAL FISHING-GROUND NORTHEAST OF SINGAPORE

(Report of the Inshore Pollution Survey Team organized by the Marine Fisheries Research Department of Southeast Asian Fisheries Development Center)

November, 1975

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PREFACE

At the request of the Marine Fisheries Research Department of the Southeast Asian Fisheries Development Center and the Government of Singapore, Japan International Cooperation Agency recently dispatched to Singapore a survey team, composed of five members and headed by Mr. Yoshihiro Machida, chief of the Water Quality Division of Tokai Regional Fisheries Research Laboratory, for carrying out a survey on pollution along the Singaporean coast. The survey including observations on a boat was conducted for a period of half a month from September 1 to 15, 1975.

With the progress of the development, the question of 'Fisheries and Pollution' has all the more gained in importance also in Southeast Asian countries. At this juncture, it is deemed timely and significant that the Marine Fisheries Research Department of the said Center played a main role in materializing a field survey on this problem.

The present report contains the findings by this survey and as such I shall be very happy if it would be of use for those persons concerned.

I should like to take this opportunity to express my heartfelt gratitude to all both at home and abroad who kindly extended cooperation in the implementation of the survey.

October, 1975

Tatsuaki Hirai
Director
Japan International Cooperation Agency

CONTENTS

CHAPTER 1 OBJECTIVES AND PROGRESS OF SURVEY

One of the major objectives of the present survey was to investigate the actual conditions of water pollution, especially in relation to the fisheries at the Johore Strait, to which keen attention has been growingly paid in Singapore today.

The other was to make preparations for ensuring an efficient expert sending program by taking up preliminary a survey on the requisite fields of experts and their terms of reference or scope of works for coping with a future need for Japan to dispatch a certain number of experts over a long-term period to the SEAFDEC countries, since the problem like Singapore's is sooner or later most likely to arise in other member countries and therefore the SEAFDEC itself will be obliged to tackle it openly after obtaining approval from the Council.

It seems useful to recall hereunder how the present survey had been motivated.

Following the event of Showa Maru, a Japanese supertanker that ran a ground and spilled out thousands of tons of crude oil off Singapore last January. the Singaporean authorities in particular have been increasingly concerned about the inshore pollution. The Singapore's port and harbor authorities (PSA), SEAFDEC's Research Department (MFRD) and the Chemical Department of the Environmental Agency of Japan decided to carry out an investigation on this matter by dividing the works among them.

In particular, MFRD became responsible for making an investigation on the relation between pollution and the fisheries in the eastern Johore Strait. Having no experts in this field, MFRD requested the Government of Japan to send those specializing in this field and a survey mission alike.

Initially, some Japanese experts had been against the MFRD dealing with such a coastal pollution problem. Later on, however, in anticipation of the likelihood of this problem to become common to the SEAFDEC nations along with their rapid industrailization and urbanization, these experts have come to assess the necessity of MFRD as a whole to tackle the question.

The present survey dealt with the Johore Strait by placing extra emphasis on the relation between cultivation of shrimp and grouper and the organic waste water, such as urban sewage and waste water discharged from pig farms. It was largely divided into three parts --- hydrography, water quality and biology.

Following is the list of members and the schedule of the survey.

Member List:

Yoshihiro Machida, Leader Water Chemist Chief of Water Quality Division of Tokai Regional Fisheries Research Laboratory, Fishery Agency.

Ryonosuke Kitamori, Bottom Fauna Biologist, Chief of Water Pollution Section, Water Quality Division, Tokai Regional Fisheries Research Laboratory, Fishery Agency.

Katsuo Okubo, Water Pollution Biologist, Senior Research Official of Water Quality Division, Tokai Regional Fisheries Research Laboratory, Fishery Agency.

Akihiko Kuwabara, Hydrologist, Postgraduate Student of the Graduate School of Faculty of Agriculture, Kyoto University

Yoshiwo Yoshida, Overseas Coordination Section of Japan International Cooperation Agency

Schedule of the Survey: September, 1975

1 (Mon.)	Departure (JAL 711)
2 (Tues.)	Visit to the Japanese Embassy in Singapore and the Singapore Office of Japan International Cooperation Agency in the morning. Visit to the SEAFDEC to as certain the objectives of the survey and make previous arrangements of schedule in the afternoon.
3 (Wed.)	Preparations for the survey, including equipment maintenance at the SEAFDEC.
4 (Thur.)	Inspection of the proposed area for survey (Eastern Half of Johore Strait) and determination of observation points.
5 (Fri.)	Observation and sample collection at the stations 4 - 8, 10, 10', 11' and 13.
6 (Sat.)	Preparations of reagents for chemical analyses, sorting of benthic animals and treatment of observed data at the SEAFDEC.
7 (Sun.)	Holiday
8 (Mon.)	Observation and sample collection at the stations 2, 3, 4, 7, 10, 14 and 15.

9 (Tue.) Chemical analyses of water samples, sorting and identification of benthic animals, treatment of observed data, and hearing on the policy of water management and the standards of waste waters in Singapore at the SEAFDEC.

10 (Wed.) Chemical analyses of water sample, sorting and identification of benthic animals, and treatment of observed data as well as the rearrangement and study of the findings at the SEAFDEC.

11 (Thur.) Ditto

12 (Fri.) Inspection at water reservoirs, piggery sties and a sewage treatment plant in the morning. Interim report on the survey at the office of MFRD of SEAFDEC in the afternoon.

13 (Sat.) Reporting the results of survey to the Japanese Embassy in Singapore and the Singapore office of Japan International Cooperation Agency in the morning. Inspection of the industrial area and a fish market in Jurong in the afternoon.

14 (Sun.) Holiday. Preparation for going home.

15 (Mon.) Return to Japan (JAL 712).

Chapter 1 of the present report is written by Yoshiwo Yoshida, Chapter 2 by Yoshihiro Machida, the first half of hydrography and water quality of Chapter 3 and 4 mainly by Akihiko Kuwahara, while the second half by Katsuo Okubo, the description on plankton of the part of biology by Akihiko Kuwahara, that on benthos and fisheries biology by Ryonosuke Kitamori and Chapter 5 by Yoshihiro Machida, respectively. We take this opportunity once again to express our sincere gratitude to Mr. Hooi, director of the MFRD of SEAFDEC, Mr. Inoue, vice direction, and all other staff of the Research Department who kindly offered various facilities and help to us for fulfilling the survey.

CHAPTER 2 BACKGROUND OF THE PROBLEM

2-1 Outline of Socio-economic Aspect and Natural Environment

The Republic of Singapore became an independent country as a member of the British Commonwealth in 1965 after having separated from Malaysia. It covers about the same area as Awajishima Island, situated between Honshu, Japan's principal island, and Shikoku, south of Honshu. Singapore's population is almost the same as that of Yokohama City, and accordingly the country is the smallest in Southeast Asia.

A pivot of the traffic linking the Indian Ocean with the Pacific Ocean, Singapore had been playing a very important role as a British colony both militarily and economically since 1819.

Singapore's economic existence lies in transit trade. However, as it can not 100 per cent depend on such a trade because of changes of international political and economic situaitons as well as a sharp increase in population, the country is now engrossed in fostering industrialization.

As to passenger transport, a shift of touristic demand from ship to airplane has resulted in leading Bangkok to topple the position so far dominated by Singapore. Ships using the Singapore port now are only those carrying cargoes.

Singapore comprises a main island at a southern tip of the Malay Peninsula and nearby 54 islets. The main island is connected to the Malay Peninsula by a 1.2km causeway. The country is located 136.8km north of the equator line in lat. $1^{o}09'$-$1^{o}29'$ N and long. $103^{o}38'$-$104^{o}06'$ E, forming nearly a semi-circle with a length of 41.8km and a width of 22.5km. Its coastal line is as short as 133.6km in length and its area is 584.3 square km.

The country has rainfall all thorugh a year with no definite difference of dry season and wet season. Rainfall is rather noticieable during the first half of the period from November thorugh January when the seasonal northeaster blows. An average daytime temperature stands at 29.4 degrees C. and an average nighttime temperature is 23.8 degrees C., showing almost no change all the year round.

Over the South China Sea, the southwester blows in summer (May through September), while the northeaster blows in winter (November through March) As a result, the oceanic current generally moves northward in summer and runs southward in winter. On the contrary, the current at the Malacca Strait flows toward the west throughout a year.

Water at the Johore Strait moves less quickly and the depth of water there is so shallow that discharging of sewage is not suited. In addition, the sea surrounding this island is not deep. At the time of spring low tide, the eastern part of the Johore Strait, which usually is 1 to 2 fathoms deep, is dried up to 2.4 km from the coast.

The Island of Singapore can be divided largely into three parts --- a central hill composed of granite chiefly, a southern part comprising shale and sandstone and the eastern part made up of sandy gravel. Central part's 33 square km flat land is preserved as water resources and nature-conservation area. The Seletar River that runs through the area is 14.5 km long and, the biggest among the rivers of the mainisland. Issuing from the head, the river flows into the Johore Strait via the Seletar reservoir. Jungles and boglands, which once existed in such areas as Pandan, Kranji and Seletar-Tampine, have been developed and changed into lands for industrial and residential uses.

The Singapore City, which has been prosperous since the old days, is located in the center of the souther part of the Singapore Island and plays a central role in politics and commerce.

2-2 Fisheries in Singapore

Singapore's per capita marine product consumption in 1973 stood rather high at about 70,000 tons as against a population of some 2,500,000. Despite this, its domestic fishing business does not play an important role so much.

About 80 per cent of such a consumption depends on raw fish hauled by foreign fishing vessels and processed marine products imported through an ordinary trade (See Fig. 2-1).

The one third of Singapore's fishermen is engaged in inshore fishery. The offshore fishery whose importance has been increasing steadily is undertaken jointly with the countries having advanced fishing technologies. Although the number of fishing vessels has declined sharply, the country is actively fostering mechanization.

The licensed ships in 1971 totaled 794, while those equipped with in-board engine amounted to 284 (33 per cent of them, however, being less than 15 tons and those with outboard engine numbered 300 and non-powered vessels accounted for less than 14 per cent. In 1962, the non-powered vessels had represented two third of the total.

Total catch reaches 15,000 to 18,000 tons. The country attained the highest record of 18,500 tons in 1962.

The fall-off of catch through in shore fisheries was attributed largely to a rapid industrialization of the coastal industrial belt for such industries as ship-building, oil refinery and land developmelt.

On the other hand, the offshore fisheries have been shooting up, making up for a drop of inshore fisheries (See Table 2-1).

Although marine products capture an important part of the animal protein intake, a weight of commercial practice in the economic importance is growing larger than that of fishing operation.

The Singaporean Government is trying to give an administrative guidance more to the development of the offshore fishery, because the in shore fishery's future is less promissing due to active industrialization along the coast and also because a dependence on imported marine products should be lessened.

Despite the governmental subsidy, an increase in the number of local fishing vessels appears almost unlikely, while cases are growing where Singapore's fishing firms conclude tie-up arrangements with their foreign counterparts having rich experience and advanced technologies.

Except for fish culture in ponds like carp, no remarkable progress has been made in the field of inland waters fisheries. Salt-water culture also is limited to shrimp.

Future of this field also is expected to undergo restraint from the land utilization of construction jobs and a large-scale social development project. However, an intensive cultivation in impounding nets and divided waters in coastal area seems hopeful and efforts are being made for the development of such fields. In addition, use of the shallow sea as a farm of raising sea mussel, oyster and sea weeds is regarded possible. In particular, sea mussel raising appears most likely.

For instance, according to the result obtained after examining shrimp cultivation, the annual raising capacity will be possible to increase from the present 250-400 kg/ha to about 600 kg/ha through an appropriate breeding density and management of predatory fish and further to 2,000-2,500 kg/ha by feeding and adequate control.

At present, half of the shrimp-culture ponds are located in Punggol area, Ubin Island and Tekong Island. The ponds are made by forming bank at bogland where part of mangrove is felled down. A water gate is opened to let water come inside simultaneously with shrimp and larval fish at every high tide, while a wire net is set down to the water gate for preventing fish from running away at low tide. By so doing, they make much use of abundant feeding organism generating in the ponds to raise shrimp big enough to be caught in four to six months.

What is more, mangrove crab which is thin when being caught is being fattened on a commercial basis, and culture of expensive fish, giant shrimp, oyster and sea mussel has been started though on an experimental stage.

As clear from the above Figures and Tables, a decline of the number, area and production of keron and shrimp ponds is conspicuous. The Johore Strait and the changi area located northeast of the Singapore Island are the important fishing grounds on which the Singapore's fishing interests pin high hope. However, these areas still faces problems. At the western part of the Singapore Island which faces the Johore Strait, in addition to a steam power plant, the Senba Wang dock and the Seletor navy base, there are a sewage treatment plant, fishing ports and a reclamation area with litter dumping.

Also, on the Malaysian bank across the strait, there watched from after something like oil tanks, quarried stone shipping piers and an industrial estate. Moreover, a dredging work is being undertaken over sailing routes.

What is the most serious to Singapore is waste water discharged from a sewage treatment plant to the Serangoon river.

It has been reported that pig-raising farmers will move to the north eastern part of the Singapore Island in the future.

2-3 Industry and Water Resource

Concerning conservation and utilization of water, we have to refer to Singapore's development plan.

In Singapore, waste water discharged from the non-industrial urban district as well as industrial plants pours into the public sewarage, while that from other areas runs into rivers and the like. As shown in the Table 2-2, both cases are subject to restrictive measures.

As Table 2-3 depicts, the country consumes water amounting to 100-110 mgd (million gallons per day) which is equivalent to 455-500 thousand cubic meters, about half of which is sent to and processed in treatment plants before being discharged.

At present, Singapore has four sewage treatment plants, two of which are carrying out a secondary treatment. They are Ulu Pandan plant and the Kim Chuan plant. The standard processing requirements of these plants are 20 ppm for BOD and 30 ppm for SS. There is no requirements as to E. coli and a chlorination treatment has yet to be applied.

Singapore is planning to set up five additional treatment plants. Of this, three will be located on the side of the Johore Strait. However, how to use treated waste water has not been worked out so far.

Water quality requirement of effluent discharged into course way is extremely severe. One of the reasons is that, Singapore's existing three reservoirs are supplied with a large quantity of water from Malaysia. Once water supply is cut, these reservoirs are said to function only three months so that a dam is being ocnstructed at the mouth of river to keep water for use.

The Kim Chuan treatment plant is discharging 138,600 cubic meters of the secondary treatment water per day to the Seragoon river. On the other hand, the Ulu Pandan plant is trying to supply the tertiary treatment water to the Jurong industrial estate as an industrial water, while at the same time giving to the secondary treatment 143,500 cubic meters of water per day.

This reflects the serious concern of Singapore an authorities about coping with the existing water shortage.

As far as the basin where a plan is being mapped out to build a dam at its mouth for securing water resources is concerned, the authorities not only set the severe restriction against effuents as stated previously, but also are forcing the pig raising farmers to move to the Serangoon river basin.

Even the pig farms undergo such strict requirements, however, treatment of piggery waste appears extremely difficult in actual cases especially when small-scale pig raising farmers are scattering.

Meantime, Singapore is working out a plan to form 10 cities, each having 300,000 population, by setting a ceilling to the population at 3,000,000 in the future (its present population being about 2,500,000). In case consolidation of sewarage is delayed, it is designed to set up a community plant.

2-4 Conservation of Fishing-grounds near the Johore Strait

In addition to these situations, due to short coastal lines and the navigation-relating restrictions, Singapore is not blessed with the usable in shore fishing-grounds.

Under the circumstances, utilization of the unexploited eastern part of the Johore Strait, its nearby inshore fisheries and fish farming grounds is an urgent need. At the same time, monitoring of the polluted degree of the nearby fishing-grounds is indispensable.

As a matter of fact, thanks largely to the eutrophication resulting from discharged water from a sewage treatment plant at the lower reaches of the Serangoon river, there are plenty green mussel *(Mytilus Viridus)* which are used as feed for raising edible and high-priced fish.

People are concerned more about the value of the *mytilus viridus* as an indicator species for monitoring environment of fishing-grounds, although some fear for the accumulation of heavy metals contained in the waste water discharged from a sewage treatment plant draws attention.

Propagation of such an organism that can become a feed for cultured fish is paving the way for developing application of feed for intensive fish culture and efforts thus have come to be made to select appropriate species for the intensive fish culture.

However, the farms for shrimp, one of the most viable fish to be affected by the eutrophication, have witnessed a decrease of shrimp and their production per unit area reportedly has been downgraded.

Therefore, it is necessary to clarify the relation between pollution and production at the nursery ground of the shrimps and the figerlings in this area. Likewise, it is required to cast light on the relation between in shore fisheries, such as in Keron, and pollution.

Also, attention should be paid to the relation between an intensive culture thorugh feeding fish and the environment of fishing-grounds.

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CHAPTER 3 FINDINGS AND DISCUSSION

3-1 Hydrography and Water Quality

3-1-1 Method

A 7-m boat equipped with an outboard motor was used for the survey on the waters.

Because of a low maximum speed of the boat, all spots for observation were divided into two parts. On September 9, a survey was made chiefly on the Serangoon river, regarded as major sources of pollution, as such spots as Sts. 4, 5, 6, 7, 8, 10, 10', 11 and 13, and on September 8 as such spots as 15, 14, 10, 7, 4, 3 and 2 (See Fig. 3-1).

It was cloudy with occasional light rainfall on September 5 while fine with slight wind on September 8. As a result, the measuring instrument for serial observation inclined at about 30 degrees. However, the correction of inclination was omitted from the data treatment.

The ECT5 salinometer produced by Toho Dentan was used for measuring water temperature and chlorinity and the EIL 1520 type DO meter was used to measure the dissolved oxygen saturation ratio, while pH was measured with a pH colorimeter for sea water.

COD of water was measured by an alkaline potassium permanganate method with 20 minutes heating, followed by iodometric titration. The relationship between the observation time on each spot and the tidal time is shown in Fig. 3-2 and 3-3.

3-1-2 Result of Survey Conducted on September 5

1) Chlorinity (See Table 3-1)

A maximum chlorinity was 16.5% at a lower layer of St. 7 and a minimum one was 13.6% at the surface of St. 13. Except for such three points as Sts. 10', 11 and 13 at the mouth of the Sarangoon River, of which chlorinity was less than 15%, no remarkable changes were reported as to the surface chlorinity.

Even at the mouths of the Seletar River and the Punggol River, the value of less than 15% of chlorinity was not monitored. The jumping layer of chlorinity was noticeable most clearly at St. 4 but became gradually ambiguous towards the inlet of the Strait, from St. 7 to St. 10 and at the same time a difference of chlorinity between the surface layer and the bottom layer was reduced.

2) Water temperature (Table 3-2)

In both horizontal and vertical directions difference of water temperature were small with a scope ranging from 28.5°C to 28.9°C.

3) Dissolved oxygen (Table 3-3)

The dissolved oxygen saturation ratios were abnormally low (less than 60 per cent) at the surface of Sts. 10', 11 and 13 which were close to the mouth of the Serangoon River.

While at the surface of the other all stations, dissolved oxygen was oversaturated. Especially, at Sts. 4, 5, 7 and 8 the valves more than 150 per cent were detected.

4) COD (Table 3-4)

Values of more than 5 ppm were observed at Sts. 4, 6, 7, 10', 11 and 13. Especially, at St. 4 and 7 of the center line of the Strait, the values higehr than that of the Sarangoon River mouth where urban waste water is discharged were detected. The highest value recorded was 10.37 ppm at St. 4.

5) pH (Table 3-5)

Values of less than 7.8 were detected at Sts. 10', 11 and 13 of the Sarangoon River mouth. While in the other observation points the values were around 8.3.

3-1-3 Result of a Survey Conducted on September 8

1) Chlorinity (Table 3-6 and Fig. 3-4)

Values of chlorinity ranged slightly from 15.35% at surface layer of St. 3 to 16.30% at bottom layer of St. 2. Waters having the chlorinity more than

16% were found to have entered into the Strait at surface layer of St. 15 towards bottom layer at St. 14.

Also, sea water of more than 16% of chlorinity was reported at Sts. 2 and 3 of the inner part of the Strait, while there were sea water with relatively low chlorinity at the surface layer of Sts. 2, 3 and 4.

The jumping layer of chlorinity was confirmed at a depth 6-8 meters from the sea level at Sts. 2 and 3 but in other areas it was less clear.

2) Water temperature (Table 3-7 and Fig. 3-5)

Changes of water temperature in the horizontal direction was 0.7°C, being larger than the result obtained on September 5.

As far as surface water temperature is concerned, the temperature at St. 15 of the inlet of the Strait was the lowest at 28.3°C. The temperature rose gradually as observation was carried out to the inner part of the Strait. It reached the highest of 28.7°C. at St. 2.

However, differences in the vertical direction were rather small at all observation points with the maximum of as low as 0.4°C at St. 3. Thus, no clear jumping layer of water temperature was not seen.

3) Dissolved oxygen (Table 3-3 and Fig. 3-6)

Except for Sts. 2 and 7, the dissolved oxygen at all observation points were over saturated at layers of a depth up to around 2 meters from the sea level. The highest figure was 116 per cent at the surface of St. 3. But, this was lower than the value of more than 160 per cent recorded by the survey on September 5.

At the middle- and lower-layer at a depth of more than 2 meters at Sts. 4, 7, 10 and 15, a saturation ratio reached more than 80 per cent. But, it declined sharply at the depth below 6 meters of St. 2 and the depth of more than 10 meters of Sts 3. Especially, the saturation ratio stood at less than 50 per cent at the depth of more than 12 meters of St. 2.

4) COD (Table 3-9)

No value higher than 5 ppm was detected. The highest value was 4.12

ppm at St. 4. In the other areas, the COD values were less than 3 ppm.

5) pH (Table 3-10)

The values of pH were between 8.1 and 8.2 at all observation points, meaning that there was little difference among the observation points.

3-1-4 Discussion

There was only a 0.6% of difference of chlorinity between the surface of the inlet of the Johore Strait and that of its innermost part. Within the strait, there was no big river where fresh water pours in. The chlorinity at the lower layer of St. 15 was only 16% level.

Also, at Sts. 14 and 15 which were close to the inlet of the strait, there was a small difference of water temperature and chlorinity between the surface layer and lower layer. This is taken to mean that the sea waters in and around this spot is well mixed in the vertical direction.

The chlorinity as observed from the result of the survey made on September 5 at the mouths of the Seletar River and the Punggol River did not decrease so sharply as to that of the Serangoon River. However, the present survey failed in clarifying whether this was due to the smaller flow of the Seletar River and the Punggol River than that of the Serangoon River or a time lag of observation hour, that is, as shown in Fig. 3-2, observation of the waters of the Seletar River and the Punggol River at high tide and that of the waters of the Serangoon River at low tide.

As clear from Fig. 3-7's T-cl diagram, the sea waters having a chlorinity of a 16% level at lower layers of Sts. 2 and 3 as the September 8 survey depicts, have a character similar to the waters that existed at the lower layers of St. 4 of the inner part of the strait on September 5.

Also, taking into account the fact that the dissolved oxygen saturation ratios at the lower layers of Sts. 2 and 3 were extremely lower than that of the other observation points, it is considered that the water mass has little movement at the lower layers of the innermost part of the strait.

As regards the water pollution of the strait, it has been pointed out that the area of Serangoon river mouth, characterized by a high COD, low pH and dissolved oxygen, is considerably polluted by an inflow of urban waste water.

However, the highest value of COD was recorded at St. 4 on both September 5 and 8.

This is because the observation was conducted at St. 4 during high tide on both days.

Another reason will be that as the propagation of phytoplankton owing to organic matters and nutrient salt discharged into the Serangoon River with urban waste waters is expected to push up COD to a higher extent, the polluted waters at the Serangoon River mouth were moved to as close as St. 4 by a current without being mixed with other waters.

The dissolved oxygen saturation ratio of more than 150 per cent shown in the result of September 5 was attributed chiefly to a photosynthesis of a large quantity of phytoplankton.

Supply of nutrient salt from the Serangoon River is regarded as playing an important role in rapid propagation of such a phytoplankton.

As a result, in overseeing pollution of the strait, attention should be paid to not only a simple contamination of water quality, such as a higher COD and a lower value of pH as well as dissolved oxygen, but also changes of biological phenomena, like redtide.

However, there was a considerable difference in the results of COD or dissolved oxygen saturation ratio between September 5 and 8. General sea conditions of the Strait and the actual situation of pollution should be made clearer in the future by undertaking more detailed survey.

3-2 Biology

3-2-1 Benthos (Bottom fauna)

1) Method of Survey

Due to complicated seabed landform of the shore in many cases, a distribution of benthos changes to a wider extent. Therefore, for making a judgement on the polluted degree, it is necessary to pick up as many stations as possible for collection.

There is no denying the fact that benthos is less affected at the shallow sea bottom near the shore because waters at the bottom layer move actively due to wind and waves and tidal influences. Rather, the considerably deep area off the shore is often polluted greatly.

Because time was limited to the present survey, the observation points were withheld to 10 by taking into consideration the above fact. Moreover, sampling was carried out at deep areas of the central part of the strait and a waterway of river mouth. (Fig. 3-8).

Date of sampling:	September 5 (Sts. 4, 5, 8, 11, 10' and 10) September 8 (Sts. 15, 14, 3 and 2)
Sampler:	Koken-type bottom sampler (Sampling area of 1/30 m^2)
Sampling method:	Mud sampled twice at each stations and separated from mud with use of a 1-mm tooth comb on board was all kept in a bottle for an immediate solidification by adding formalin. The animals visible from the naked eye were picked up at the research laboratories for classification and counting.

2) Result and discussion

An observation record of the gathering of bottom sediment is shown on Table 3-11 and Fig. 3-9. Most of them were muddy. At St. 4, containing sandy mud and clayey, while at St. 11 clayey and carbonized bark and shells were mixed. The former was attributed to a dredging work being undertaken at the strait and the latter to a reclamation for building a pond for cultivation.

St. 10 was a sand- and mud-rich area but not clayey. As referred to later, unlike St. 4, this area had a plenty of bottom fauna. A reference to a chart led to an estimation that this area formed a complicated landform equal to a small sandbank. Generally, as a coarse bottom area indicates a good movement of water at the lower layer, this area is supposed to have special conditions.

It was confirmed that in the inward part of the strait and the river mouth the bottom mud was black and the river mouth had a deposit of humus apparently due to the mangrove.

Supposedly, the bottom area of these places have rich organic matters in the bottom composition and are highly stationary and in a position close to reduction. (Table 3-11 and 3-12 and Fig. 3-9).

The survey in the tropical area was the first experience for the writer and a survey period was too short to make an analysis other than family or genus for most of anumals picked up. The result of such a sampling is shown in Table 3-12.

A basic difference appears to exist in the number and constitution of bottom fauna between the tropical zone and Japan which is located in the temperate regions. What is more, data and records are reticent about quantitative survey in the tropical regions. As a result, it is questionable to make an estimation on the polluted degree of the area concerned from a distribution of bottom funna. However, the result of the survey is to be examined here based on the fact and knowledge obtained along the shore of the Japanese islands.

Generally, the kind and number of bottom fauna were small with a relatively high percentage of mollusk and a lower ratio of crustacean. This is taken to indicate the present water area has a strong character of being an inside bay and water mass at the bottom area is not so fluid.

However, the face that a large number of the remains of such mullusk as Fluvia, Nuculidae, Neuulanidae and Dentalliidae believed to have died very recently has been sampled at many stations shows that the survey was carried out at the time when there are few animals living there.

In evaluating the degrees of pollution thorugh bottom fauna, what constitutes a barometer are their number of species an individual percentage classified as to animal group, a biotic index (number of individuals/number of species), a dominance diversity and indicator species.

First, a distribution of number of species is shown in Fig. 3-10. It depitcts existence of small number of species at a depth 10 meters from the sea level at the strait. In particular, no species were sampled at least at two stations at the inward part of the strait. At the inlet of the strait (St. 15) and St. 10 having a special feature as mentioned previously, a relatively large number of species were sampled with the number standing at 6 and 15, respectively. At Sts. 4 and 14, only one to two species were sampled.

On the contrary, at shallow estuary the number was slightly higher at 3 to 29 kinds and the largest at St. 11 which has been characterized by a special feature at a bottom sediment.

However, only one species was picked up at the mouth of the Serangoon River (St. 10').

Due to smaller bottom fauna as a whole, and irregular changes of other items except for the species, detailed examination was omitted. The fact that a biotic index became higher at the mouth of the river indicates that a simplification of benthic community is developing and their environment is being deteriorated.

Unlike the fresh water area, indicator species for organic pollution over the coastal areas were extremely less. In other words, they were limited to such two polychaeta as *Capitella capitata* and *Prionospio pinnata.* The former are found mostly along the coastal areas being largely affected by fresh water. It was not sampled at the recent survey. Two individuals of the latter were sampled at the mouth of the Punggol River (St. 8), meaning that there are many organic matters at the bottom sediment.

As stated previously, the recent survey poses several problems because it was made on the tropical zone and the sampling stations were limited to a small number. Thus, it appears too dangerous to proceed with an estimation. Following is a distribution of water area based on Kitamori (Fig. 3-11) (1972).

Azoic region:	Sts. 2 and 3.
Healthy region:	St. 15. Although the normal bottom fauna over the present water area has not been clarified, data on geographic position, bottom sediment and bottom fauna available at the stations have led to an estimation that the present water area is rated as nearly a healthy bototm.
Polluted region*:	Sts. 4, 10' and 14. Only one to two species

were sampled. These were areas whose stratification environment was destructed next only to the azoic region in scale.

Eutrophic* and supernutrited region*: Sts. 5, 8, 11 and 10. Of them, only three species were sampled at St. 5.
Although being designated as a eutrophic region with the highest biotic index, these were in a state close to a polluted region. The number of species were more at Sts. 8, 11, 10 than in the healthy region, and these stations are located in the eutrophic and supernutrited region. St. 11 where the biotic index is high seems to be in a state close to the polluted region while St. 10 whose biotic index is low being in a state close to the healthy region, respectively.

It is difficult to judge the environmental conditions of the three rivers from the result of such a poor survey. In order to do so, a survey should be carried out further in the future. However, although the Serangoon river's mouth is most shallow by referring to a chart, it has been designated as a polluted region. This may indicate that water flow and organic matters in this river are larger than those of other rivers.

As far as the result of this survey is concerned, bottom fauna was extremely small in number as a whole, meaning that the environmental conditions at the bottom areas are inadequate.

Various factors can be given as the reason of this. Among them are a less fluid movement of water at the bottom area, an accumulation of humus, including mangrove, and an artificial pollution. However, what kind of role these factors are playing at each water area depends largely on the future survey.

If this reasoning is not wrong largely, along with an increase in a burden of pollution in the future, these water areas are in a natural condition dangerous enough to sharply deteriorate the environmental condition of the bottom area.

3) Reference

Kitamori R.,: Faunal and Floral changes by pollution in the Costal Waters of Japan, The 2nd International Ocean Development Conference Preprints, Vol., 1, 1972.

3-2-2 Fishery Biology

The latest investigation failed in carrying out a field survey of the biology other than benthos. As mentioned in the previous chapter, efforts have been concentrated on the fishery biology by collecting data, and investigating actual performance with the eventual aim of learning the present situations as much as possible. Therefore, the fishery biology are going to be referred to briefly hereafter.

The in shore fish catch accounts for nearly 20 per cent of Singapore's fish catch. The water areas mentioned in this report constitute a major part of it. As the previously drawn Table 2-1 indicates, companies and the catch involved in the Kelong, most representative fishing operation of the in shore fishery, have been declining gradually in recent years. This is attributed largely to a social background as well as civil engineering works along the coastal waters, such as dredging and plant construction, and inflow of sewage. Among others, inflow of sewage is expected to increase in the foreseeable future.

Under the situation, an importance of protection and developmelt of the inshore fishery has been recognized, opening the way to start the present survey.

Bag net operated at the river mouth, crab lift net used for mangrove crab and pond cultivation of fishes, shrimp and crab are important inshore fishery next only to the Kelong operation. However, researches on operation, catch and the biological factors of fishes caught have not been studied fully.

The green mussels *(Mytilus viridis)* have increased sharply at the mouth of the Serangoon River in recent years. Such a growth has been regarded as to have close connection with the growing polluted water, including urban waste water. Recently, however, attempts have been made to use the green mussels as foodstuff or feedstuff by cultivating them, while basic researches are commenced for utilizing them as an 'indicator' biology for monitoring the degrees of eutrophication or for controlling the eutrophication by having it absorbed excessive nutrient salts.

CHAPTER 4 FUTURE SURVEY PLAN

4-1 Hydrography

The present survey was a preliminary one. In the future, it will be required to undertake detailed survey on overall sea conditions, including water temperature, a salinity distribution structure and a fluid pattern, and to clarify a flauidity and diffusion of polluted water for assessing hydrographical feature of the water in and around the Johore Strait.

4-1-1 Temperature and salinity distribution in and around Johore Strait

At the water area with a narrow inlet but a wide and deep tract like the Johore Strait, water temperature and a salinity distribution vary greatly in accordance with a difference in tide sea level between high tide and low tide and changes of the volume of fresh water pouring into the strait from rivers.

In the present survey, the observation time lasted long and an influence caused by a gap of tide was exercised. As a result, no detailed distribution pattern of temperature and salinity has been confirmed. Thus, the survey on the distribution of temperature and salinity within the strait should be carried out in a short period of slower current flow in high and low tide, thus clarifying a distribution pattern in both high and low tide.

4-1-2 Follow-up Research on Polluted Water Discharged From the Serangoon River

The present survey has pointed out that there was the likelihood of the relatively polluted water mass from the Serangoon river being washed away to an area close to St. 4 of the strait by a flood streams.

For the purpose of supervising the water quality of the Johore Strait in the future it will be important to clarify a movement of polluted water discharged from the Serangoon river.

Movement and diffusion of polluted water mass are subject chiefly to the volume of discharged waste water and a speed of tidal flow. As a result, it is required to carry out a survey on a fluidity pattern at each tide by taking into consideration the change of a tidal level and the volume of river water simultaneously.

As to the study of the movement and diffusion of water mass, there are such possible methods as chasing floating objects, like drifting pole or bottle, and spreading dyestuff.

To get a fluidity pattern of water, current velocities at individual points within the strait at each tide should be examined with use of a current meter. At the same time, it is necessary to carry out a survey consecutively for more than 24 hours or various observation points both inside and outside of the strait and learn specific current movement within the strait with use of the method for frequency analysis of current speed.

4-2 Water Quality

As clear from the preliminary survey of this time, water pollution of the Johore Strait is attributable mainly to the contaminated organic matters caused by sewage discharged into the Serangoon river.

As a result of the contamination of such organic matters, a situation of low oxygen or non-oxygen develops. Moreover, with a secondary pollution involving generation of hydrogen sulfide, the environment is likely to be destructed further.

4-2-1 To Evaluate the Present Status of Organic Pollution, Water Qualitative Survey in Whole Region of the Strait is Necessary

In this case, one of the major objectives will be to carry out a follow-up research on what area the polluted organic matters pouring in from the Serangoon river will reach at high tide or low tide and what kind of density distribution these organic matters will show.

When considering the limitation on manpower and equipment, it would be better first to focus on the measuring of COD as an indicator of polluted organic matters, with the addition of the, measuring of transparency, DO and pH, then to undertake observation at each tide in the rainy season and the dry period respectively so as to obtain a pattern of pollution under each situation.

If possible, it will be preferable to measure an ammonia density in water and hydrogen sulfide in bottom mud chiefly in the Serangoon River.

4-2-2 **As the Second Step, with the Organic Matters being Involved, It will be Beneficial to Conduct a Survey on Excessive Nourishment Beforehand**

Like COD, the distribution survey on PO_4-P, NO_2-N and NO_3-N is to be carried out at each tide. Also, if possible, it will be favorable to carry out measuring and obtain data on all phosphorus and nitrogen.

4-2-3 **For Evaluating the Chemical Data Obtained, It is Required to Confirm COD and Other Normal Values at the Areas Very Close to the Coast in the Tropical Zone**

As to unpolluted mangrove area and the coastal areas of a special character, a water quality survey as mentioned in 4-2-1 and 4-2-2 will be favorable.

BOD has been generalized in the sewage relating organizations and the research on polluted organic matters in inland waters. However, in case waste water is discharged into sea, it is a question to analyze dissolved oxygen density using the BOD value of crude sewage under a standard method because the micro-organisms and other conditions related to the analytic process of organic matters in fresh waters are different from those in sea waters.

For the purpose of tracing the diffusioned organic waste water, BOD is not suitable in sea waters. This is because though BOD changes in the sea waters just like COD does, the former is more troublesome than the latter in conducting measuring.

On the contrary, in analyzing changes of dissolved oxygen volume in sea waters, proper use of the BOD value to sea waters is worth doing. There may be several points, including measuring conditions suited for observation spots, that should be reexamined more.

4-3 **Biology**

4-3-1 **Plankton**

It is important to clarify the role and ecology of plankton as a biological indicator of sea area pollution as well as animals for feeding coarse fish.

The present survey did not cover plankton. But, the result of dissolved oxygen leads to a consideration that phytoplankton is proliferating at a high density. This indicates that there is the lkelihood of the red tide generating within the Johore Strait due to harmful phytoplankton right now.

A methdo of research and investigation concerning a mechanism of the red tide generation and the ecology of plankton as animals for feeding coarse fish has yet to be established. However, at least following two basic data should be collected and analysed.

First, seasonal changes and a distribution pattern of the dominant species of zoo-plankton and phytoplankton within the strait are made clear thorugh periodic investigation and data obtained in the past. This should be followed by formation of a list for the appearing species.

After dividing the strait into two or three parts based on the above data and a distribution pattern of water temperature, salinity and nutrient salt, seasonal ecological changes of plankton at fixed points of individual parts of the strait should be obtained and examined in the manner of corresponding to the characters of sea waters, such as water quality. In such a survey, sample collection should preferably be carried out as frequently as possible.

4-3-2 Benthos

First stage: Detailed distribution of bottom fauna still unfamiliar through the present survey should be investigated. For instance, the sampling stations are fixed as many as possible in the strait by placing emphasis on two to three rivers, centering on the Serangoon River, with two to three sampling in separate seasons, if possible. As a taxology relative to bottom fauna is not widespread in general, knowledge in connection with bottom fauna should be obtained in collaboration with other research laboratories.

Second stage: Based on the result of the above basic survey, stations suited for monitoring and season for sampling will be selected to carry out the survey conitnuously.

In this case, unlike water quality's distribution, due to complicated undersea landform, a slight slippage of a sampling station tends to lead a distribution of bottom fauna to change a little bit.

Thus, the larger the number of the sampling stations, the better the result obtained. Permission may be granted to one sampling at one season.

4-3-3 Fishery Organisms

Both plankton and stationary benthos offer several advantages to the methods of evaluating and monitoring the degree of marine pollution --- the former as an indicator of water mass and the latter as an indicator of the polluted environment of the bottom layer.

From the viewpoint of fishery, it is preferable that these organic groups are useful as an indicator of an influence exercised by pollution over fish catch. In Japan, too, efforts have been made for this. However, the mutual relation between pollution and fishery organisms has not yet been made clear.

When it comes to the fishes with a stronger nature of movement and migration than plankton and benthos, there are many difficulties of even finding ways to sample and investigate as well as fixing spots for quantitative survey. Nonetheless, as long as a pollution monitoring is aimed at protecting and developing the inshore fishery, it will be quite natural to place emphasis equal to or bigger than the aforementioned organic groups on research on fishery organisms.

First stage: As to kelong, bag net, crab lift net, farming ponds and green mussels, measures should be taken for learning the actual conditions by areas of installation place, operation situation, catch, distribution and growth, if not, outline of catch, at least.

Second stage: Representative kind of fishery and fishermen's house should be selected by each major area to consolidate catching statistics as precise as possible and carry out suitable biological measuring.

Among organic groups, such as plankton, benthos and fishery organisms, crustaceans are said to be highly susceptible to pollution so that it will be one possible way to give priority to the output catch and growth of mangrove crab and shrimp cultured in ponds.

In Japan, *Mytilus edulis* is being used as a biological indicator of eutrophication. A survey on a distribution, number and growth of the green mussls already has got under way. This will be an effective method.

Statistics on the catch of fishermen is basically an important item. This is subject to the changes of operating conditions and efforts for fishing as well as fluctuations of social background. It thus is difficult to distinguish these changes from those resulting from deterioration of environmental conditions.

As a result, simultaneous use of experimental methods, including a survey on fish school by the use of a fish finder, and tentative hauling with actual fishing instruments, such as the Petersen fingerling net (a small dragnet) will be more effective.

CHAPTER 5 REQUIRED MANPOWER AND EQUIPMENT

To follow up the survey in the future, various persons are requested to be dispatched. Aside from those Japanese experts now working for the Marine Fisheries Research Department of the Southeast Asian Fisheries Development Center, their proposed successors and the one specializing in hydrography who are said to have been requested additionally, the Department will need at least a coastal water pollution chemist. Judging from the question proper to water pollution in the area concerned, preferable person will be a scientist with much experience and knowledge on water analysis, primary production and eutrophication, or the one having ability to master them completely.

Moreover, to carry out a chemical analysis of water and bottom mud, following equipment will be required: spectrophotometer enabling use of a long cell, electric dryer, electric furnace, rotary evaporator, a set of semi-micro kjeldahl apparatus reagent chemicals for analysis and glass instruments.

Among these, the spectrophotometer will be indispensable.

Table 2-1. Production of various fisheries

	Local production of fish (ton)				
Year	Brackish W. pond	Fresh W. pond	Inshore[1]	Offshore	Total
1965			4,345	6,627	10,972
1966			4,602	13,855	18,457
1967			4,684	13,527	18,211
1968			4,834	12,483	19,317
1969			3,409	13,589	16,998
1970		866	2,789	14,661	18,316
1971	191	726	2,651	11,642	15,210
1972	185	680	3,378	11,419	15,662
1973	130	580	5,685	12,265	18,660

Note: 1); Kelong, drift net, beach seines & fish trap

	Kelong fisheries in Singapore		
Year	No. of kelong	Catch, t	Catch/kelong
1965	181	2,300	12.7
1966	161	2,400	14.9
1967	143	2,500	17.5
1968	132	2,400	18.2
1969	126	1,800	14.3
1970	117	1,500	12.8
1971	112	1,300	11.6
1972	106	2,000	18.9
1973	96	3,100	32.3
1974	91		

Table 2-2. Water quality standards for trade effluent discharge

Item of analysis	Sewers	Water course
	Units in milligram per litre or otherwise	
1. Temperature of discharge	110°F (43°C)	43°C
2. Colour	--	7 Lovibond Units3)
3. pH value	6 – 9	6 – 9
4. B.O.D. (5 days at 20°C)	400 (1,200)5)	50
5. C.O.D. (dichromate value)1)	600 (1,800)5)	1003)
6. 4 hour PV2)	200	40
7. Total suspended solids	400 (1,800)5)	50
8. Total dissolved solids	1,000 (3,000)5)	1,0003)
9. Alkalinity as $CaCO_3$	2,000	--
10. Chlorion Cl^-	1,000	400
11. Sulphide ($S^=$)	1	0.2
12. Sulphate ($SO_4^=$)	600	50
13. Anionic detergent as manexol O.T.	30	15
14. Grease and oil4)	30 (60)5)	5
15. Simple soluble cyanide	1	0.1
16. Complex cyanide	1	--
17. Ferro-cyanide	3	—
18. Barium, selenium, tin	10	--
19. Iron	50	5
20. Arsenic	5	0.5
21. Beryllium	5	0.5
22. Boron	5	0.5
23.* Cadmium	10	0.1
24.* Chromium (trivalent or hexavalent)	10	0.1
25.* Copper	5	0.1
26.* Lead	5	0.1
27.* Mercury	10	0.1
28.* Nickel	10	0.1
29.* Silver	5	0.1
30.* Zinc	10	0.1
31.* Metals in total	10	0.5

Notes: * The concentration of toxic metal shall not exceed the limits as shown, individually or in total

1) This value may be 2 – 5 times of the value obtained by acid-permanganate method
2) Consumption of permanganate (1/80N) at room temp. for 4 hrs.
3) Severe than Japanese standard
4) CCl_4-method. Includes all of mineral, plant and animal oil
5) Extra fee is necessary to get permission, but the exceptions are tentative ones

Table 2-3. Consumption and discharge of water

Consumption			
	Total consumed	Discharge into sewers	Discharge into open drains
Domestic	45 mgd	27 mgd	18 mgd
Industrial	25	10	15
Government and other agencies	35	20	15
Others	5	-	5
Total	110	57	53

Discharge		
Sources	Quantity	Quality of discharge
Final effluents from sewage treatment works	50 mgd	Very good
Small sewage treatment plants	7	Good
Industrial discharges	15	Very bad
Government and other agencies	10	Doubtful
Hawkers and markets	5	Very bad
Washings of clothes, etc.	6	Bad
Sullage water from kampongs, etc.	12	Bad
Others	5	Doubtful

Table 3-1. Chlorinity (‰) observed on Sept. 5th

Station No. / Depth (m)	St.4	St.5	St.6	St.7	St.8	St.10	St.10'	St.11	St.13
0	15.45	15.20	15.30	15.70	15.45	15.95	14.65	14.05	13.60
1	15.45	15.25	15.30	15.70	15.40	16.00	14.70	14.10	13.90
2	15.45	15.30	15.30	15.65	15.50	16.00			
3	15.45	15.30	15.25	15.65		16.05			
4	15.45	15.40	15.35	15.80		16.10			
5	15.45			15.80		16.15			
6	15.45			15.85		16.15			
7	16.00			15.90		16.25			
8	16.00			15.90		16.25			
9	16.05			15.95		16.25			
10	16.10			16.00		16.35			
11	16.35			16.00		16.40			
12	16.35			16.30		16.45			
13	16.35			16.45					
14	16.35			16.50					
15	16.35			16.50					
16	16.40								

Table 3-2. Water temperature (°C) observed on Sept. 5th

Station No. / Depth (m)	St.4	St.5	St.6	St.7	St.8	St.10	St.10′	St.11	St.13
0	28.8	28.9	28.9	28.7	28.9	28.7	28.7	28.7	28.7
1	28.9	28.9	28.9	28.7	28.9	28.7	28.7	28.7	28.8
2	28.9	28.8	28.8	28.7	28.8	28.7			
3	28.8	28.8	28.8	28.7		28.6			
4	28.8	28.8	28.7	28.7		28.6			
5	28.8			28.7		28.6			
6	28.8			28.7		28.6			
7	28.8			28.7		28.6			
8	28.8			28.6		28.6			
9	28.8			28.6		28.5			
10	28.8			28.6		28.5			
11	28.7			28.7		28.5			
12	28.7			28.7		28.5			
13	28.7			28.6					
14	28.7			28.6					
15	28.7			28.6					
16	28.7								

Table 3-3. Saturation ratio (%) of dissolved oxygen observed on Sept. 5th

Station No. / Depth (m)	St.4	St.5	St.6	St.7	St.8	St.10	St.10'	St.11	St.13
0	180	152	144	164	166	106	57	52	49
1	174	160	141	168	162	107	64	48	52
2	160	126	124	165	150	99			
3	140	106	116	165		96			
4	140	101	102	156		91			
5	140			152		88			
6	140			148		84			
7	104			136		83			
8	93			114		82			
9	94			112		82			
10	92			110		78			
11	81			110		76			
12	80			104		76			
13	79			99					
14	76			91					
15	76			89					
16	72								

Table 3-4. COD (ppm) observed on Sept. 5th

Station No. / Depth (m)	St.4	St.5	St.6	St.7	St.8	St.10	St.10'	St.11	St.13
0	10.37	2.62	6.44	7.78	1.50	3.46	5.52	6.01	7.11
1.5						-			8.56
5						2.36			
11						2.43			

Table 3-5. pH observed on Sept. 5th

Station No. / Depth (m)	St.4	St.5	St.6	St.7	St.8	St.10	St.10'	St.11	St.13
0	8.30	8.30	8.20	8.35	8.30	8.25	7.75	7.65	<7.60
1.5						—			7.75
5						8.15			
11						8.15			

Table 3-6. Chlorinity (‰) observed on Sept. 8th

Station No. / Depth (m)	St.2	St.3	St.4	St.7	St.10	St.14	St.15
0	15.40	15.35	15.65	15.70	15.90	15.80	16.00
2	15.45	15.35	15.60	15.70	15.90	15.95	16.00
4	15.50	15.40	15.60	15.70	15.90	15.95	16.00
6	15.50	15.55	15.60	15.70	15.90	16.00	16.05
8	15.90	15.80	15.75	15.85	15.90	16.05	16.10
10	16.00	15.90	15.90	15.85	15.90	16.05	16.10
12	16.20	15.90	15.90	15.90	15.90	16.10	16.20
14	16.30	16.05	15.90	15.90	15.90	16.10	16.20

Table 3-7. Water temperature (°C) observed on Sept. 8th

Station No. / Depth (m)	St.2	St.3	St.4	St.7	St.10	St.14	St.15
0	28.7	28.6	28.5	28.3	28.3	28.4	28.2
2	28.7	28.5	28.5	28.3	28.3	28.4	28.4
4	28.6	28.3	28.4	28.3	28.3	28.4	28.4
6	28.6	28.3	28.4	28.3	28.3	28.4	28.1
8	28.6	28.6	28.4	28.3	28.3	28.4	28.1
10	28.7	28.6	28.4	28.3	28.2	28.4	28.1
12	28.7	28.6	28.4	28.2	28.2	28.4	28.0
14	28.7	28.7	28.4	28.3	28.2	28.4	28.0

Table 3-8. Saturation ratio (%) of dissolved oxygen observed on Sept. 8th

Station No. / Depth (m)	St.2	St.3	St.4	St.7	St.10	St.14	St.15
0	97	116	113	95	112	108	103
2	96	114	112	94	108	103	100
4	85	108	104	94	94	101	98
6	68	91	96	90	94	98	96
8	59	82	88	88	93	98	95
10	53	76	87	87	92	98	95
12	53	67	85	90	90	97	94
14	34	58	84	90	90	96	94

Table 3-9. COD (ppm) observed on Sept. 8th

Station No.	St.3	St.4	St.7	St.10	St.14	St.15
O m.	2.79	4.12	2.63	2.87	1.92	1.57

Table 3-10. pH observed on Sept. 8th

Station No. / Depth (m)	St.2	St.3	St.4	St.7	St.10	St.14	St.15
0	8.1	8.1	8.2	8.2	8.2	8.1	8.2

Table 3-11. Depth and sediment

St.	Depth (m)	Sediment		Remarks
2	16.0	M	black	
3	17.0	M	black (surface)	
4	18.0	M · Sa, clay	grey	dredged?
5	4.7	fin, M	black	
8	3.0	fin, M	black, fine humus	
11	1.5	M · Sh, clay	grey, humus	dredged?
10'	1.5	M	black, fine humus	
10	15.0	M · Sa	grey	Sand bank?
14	18.0	M	grey	
15	23.0	M	grey	

M: Mud, Sa: Sand, Sh: Shell

Table 3-12. Distribution of bottom fauna in each stations

Species	St.	2	3	4	5	8	11	10'	10	14	15
Polychaeta,	*Nephtys*			4					1		
	Diopatora			3			18		6		2
	Glycera alba?				1						
	Telepsavus costarum?				45	3	2		2		
	Ancistrosyllis					68	15		2		
	Scoloplos					10					
	Aricia					2					
	Polynoidae					6			1		
	Glycera					4	4				
	Prionospio pinnata					4					
	Hesionidae sp. A					1					
	Poecirochaetus						1				
	Owenia fusiformis						1				
	Terebellidae						1				
	Ciratullidae						1				
	Chrisopetaridae						1				
	Polydora						1				
	Prionospio cirifella?						16				
	Nereidae						1		1		
	Prionospio marmgreni?						1		1		
	Spionidae						1				
	Paraonis						1				
	Capitellidae						1				
	Hesionidae sp. B								2		
	Marphysa								1		
Pelecypoda,	*Fulvia*				1,500		11	35	2		
	Musculus senhousia?						11		2		
	Solen sloani?						7				
	Macoma						1		1		1
	Lucinidae						1				1
	unknown						2		2		
	Modiolus						3				
	Tapes						1				
	Nuculidae									1	13
	Nuculanidae										3
Gastropoda,	Stenothyra						3				
Crustacea,	Shrimp					4					
	Amphipoda						18		5		
Echinodermata,	Brittle star					55	1		13		2
Others	*unknown*					1	1				
	Sea anemone						1				
Total	Species	0	0	2	3	11	29	1	15	1	6
	Individuals	0	0	7	1,546	158	127	35	42	1	22
Biotic index (Individuals/Species)		-	-	3.5	515.3	14.3	4.3	35.0	2.8	1.0	3.6
% of individuals,	Polychaeta	-	-	100.0	2.9	62.0	51.9	0	40.4	0	9.0
	Mollusca	-	-	0	97.0	0	31.4	100.0	16.6	100.0	81.8
	Crustacea	-	-	0	0	2.5	14.1	0	11.9	0	0

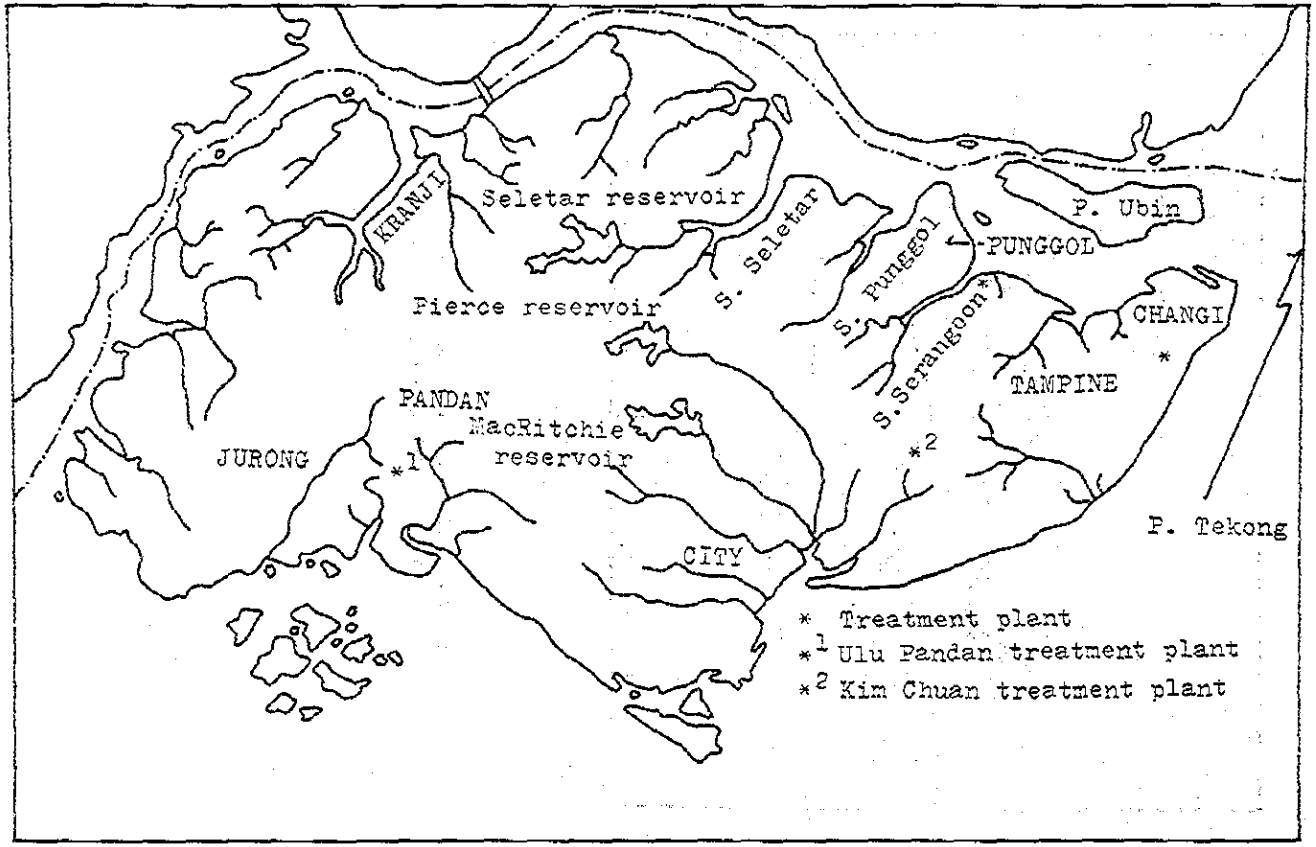

Fig. 1. Singapore

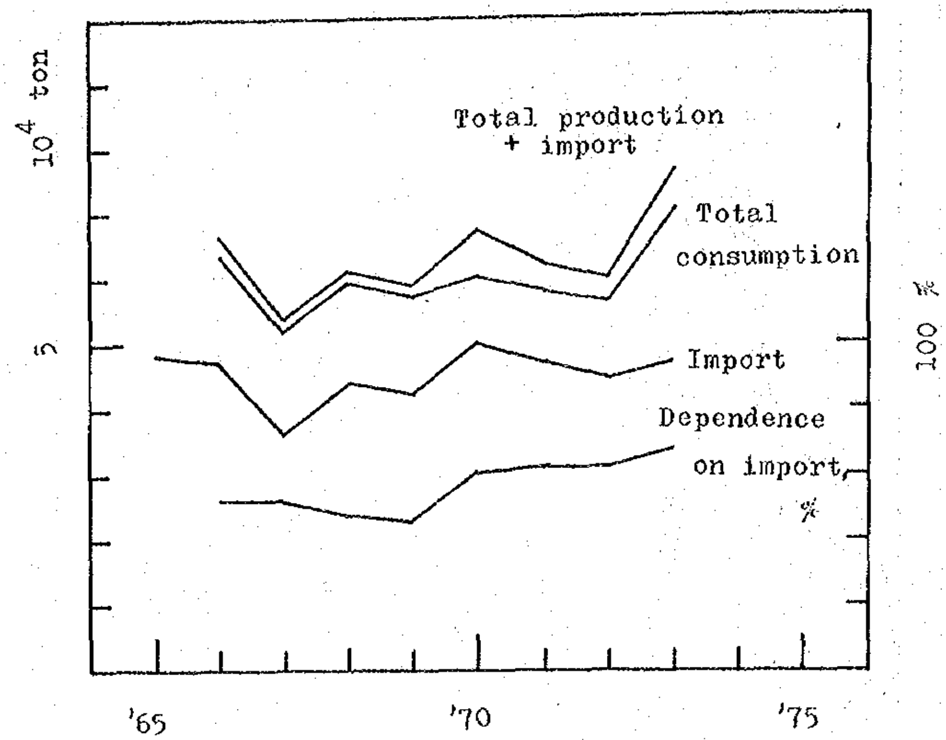

Fig. 2-1. Production, import, and consumption of fishery product, and dependence on import

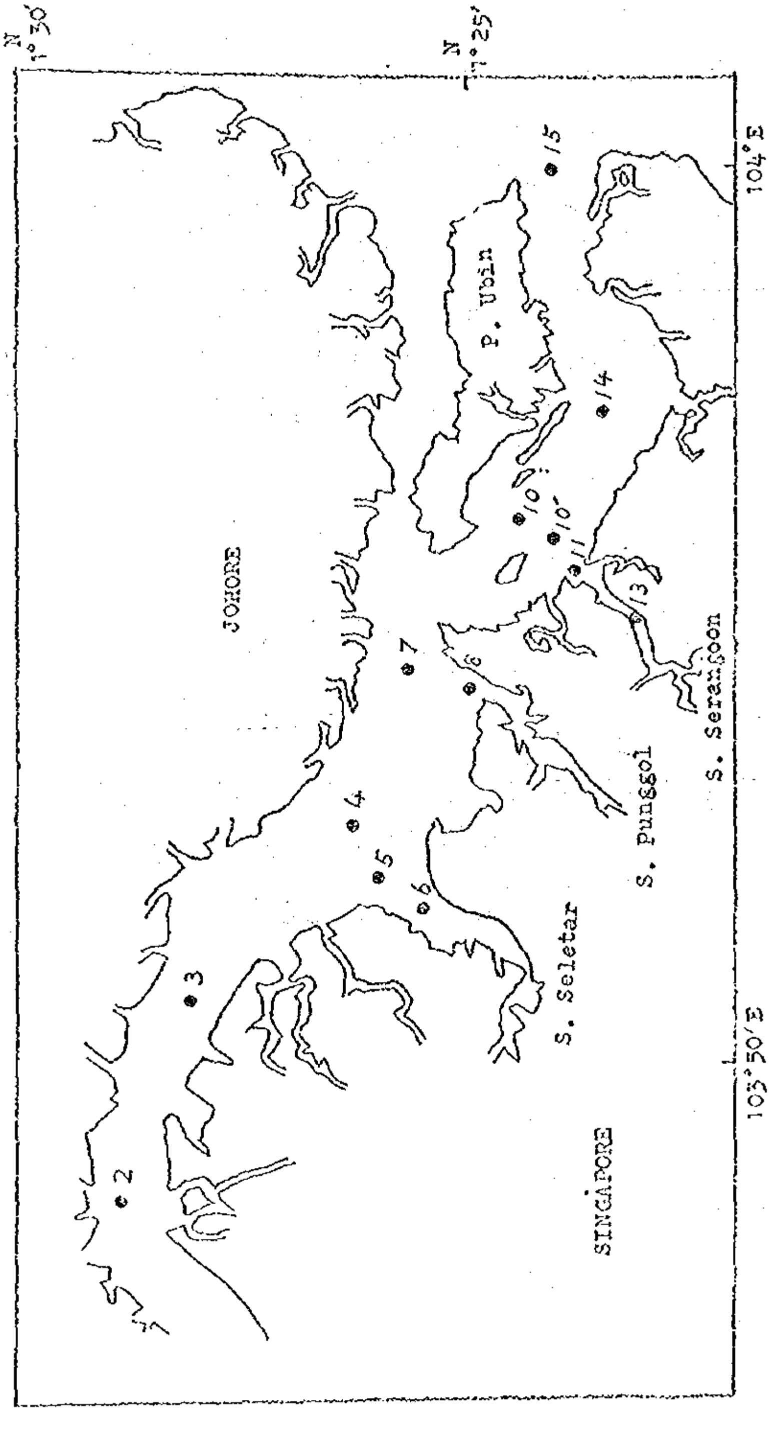

Fig. 3-1. Stations of observation

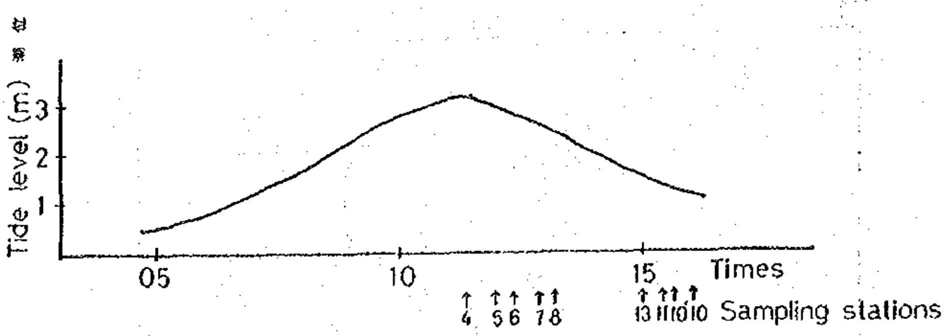

Fig. 3-2. Observation time and tide level on Sept. 5th

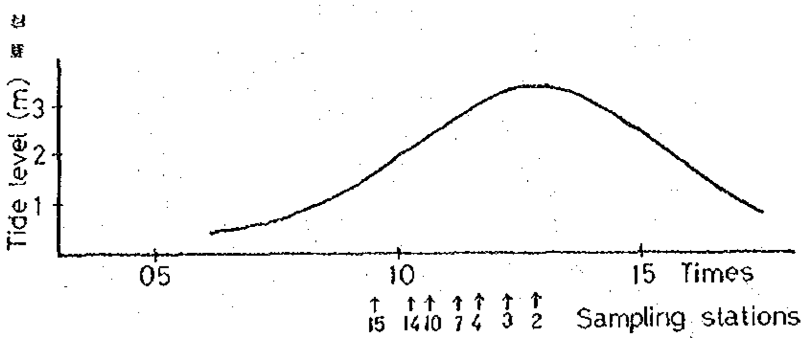

Fig. 3-3. Observation time and tide level on Sept. 8th

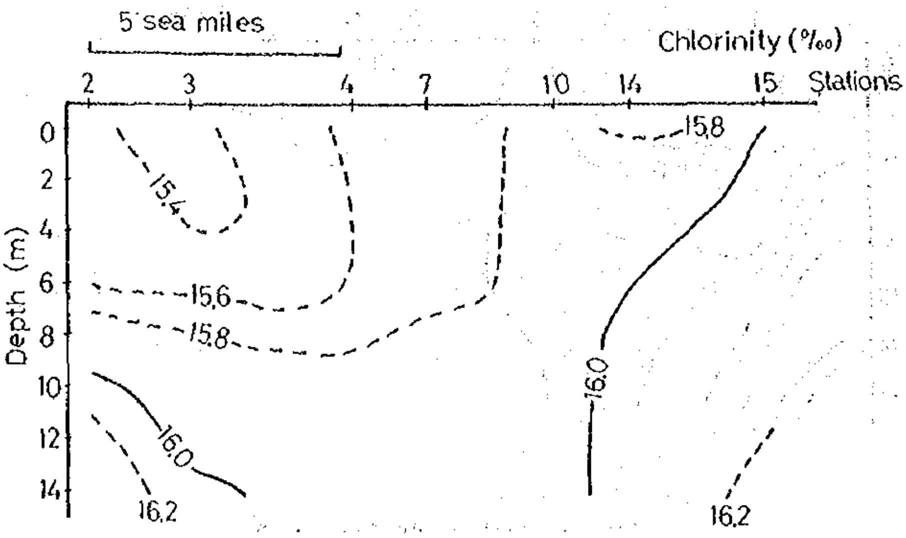

Fig. 3-4. Cross section of chlorinity

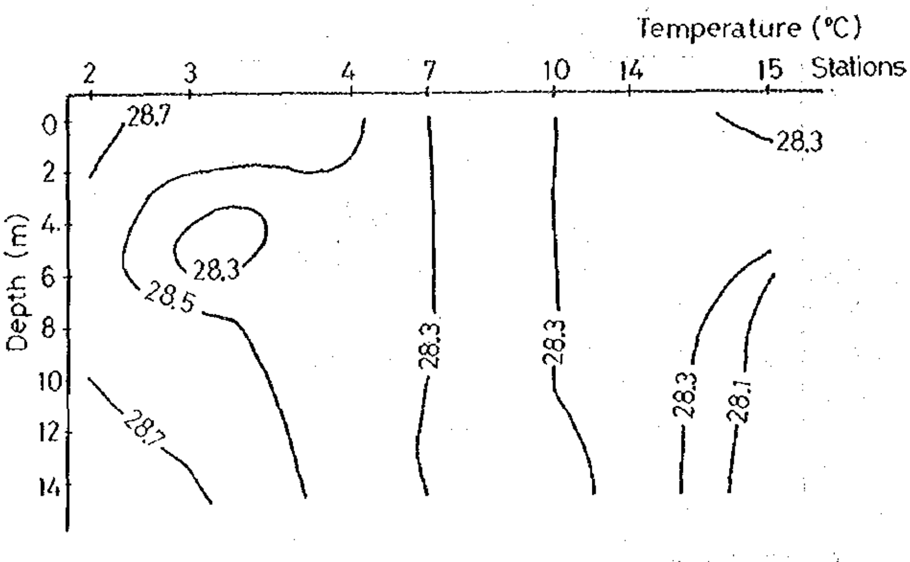

Fig. 3-5. Cross section of water temperature

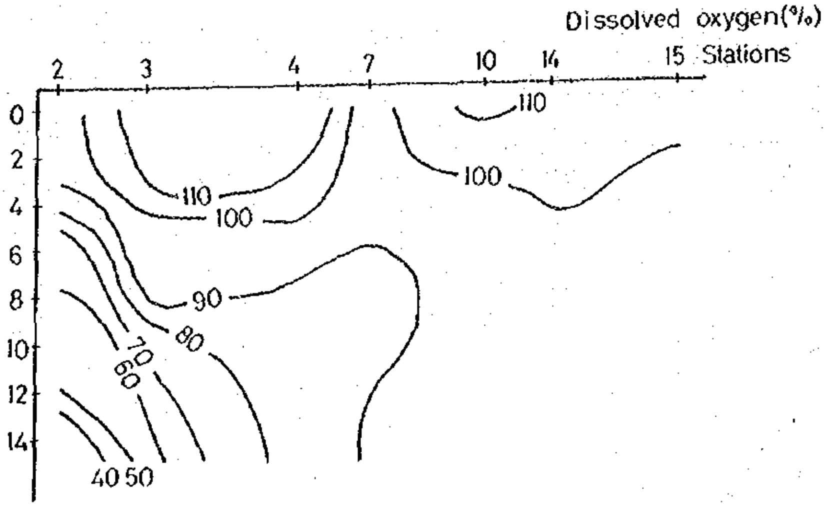

Fig. 3-6. Cross section about saturation ratio of dissolved oxygen

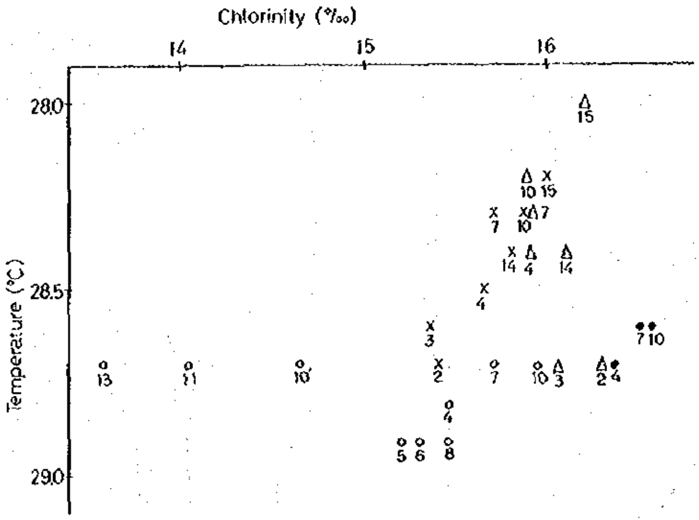

Fig. 3-7. T—Cl diagram

○ Surface on Sept. 5th ● 12 m layer on Sept. 5th

× Surface on Sept. 8th Δ 14 m layer on Sept. 8th

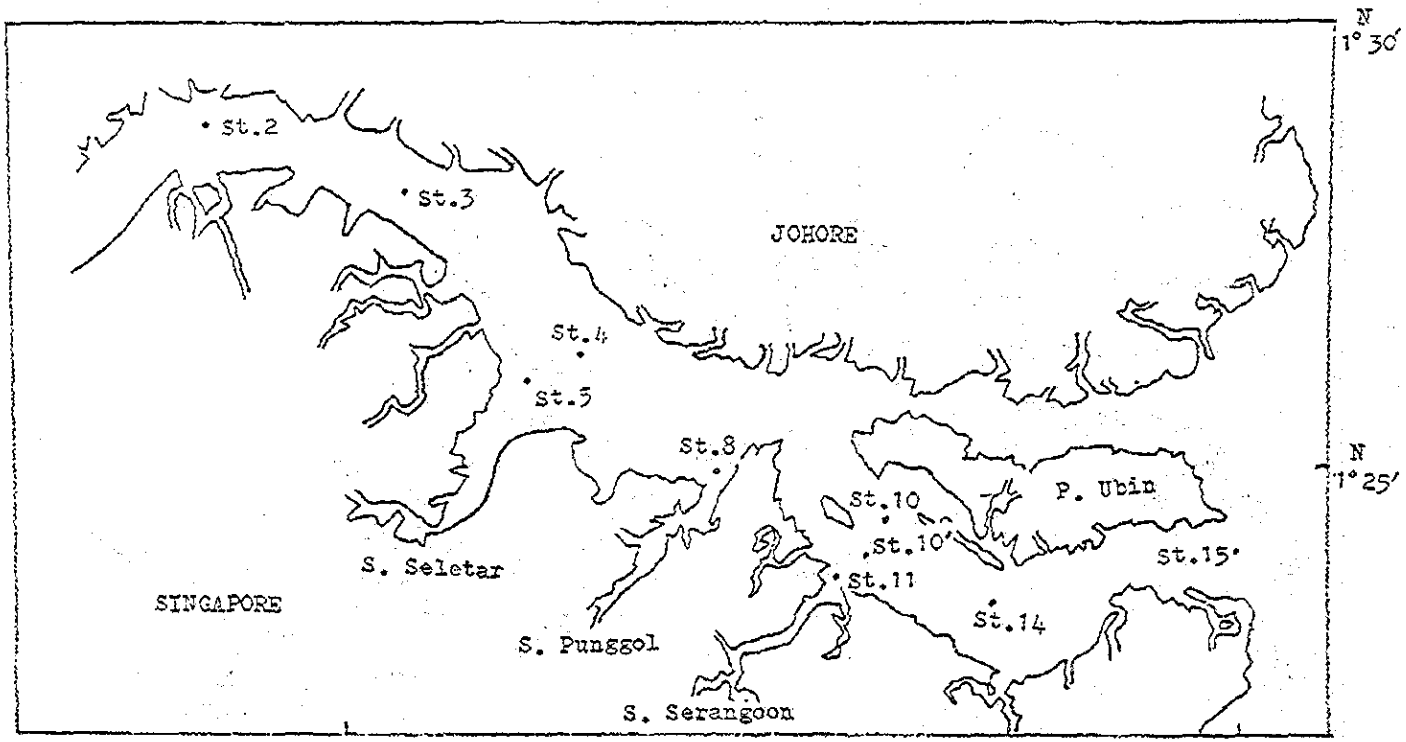

Fig. 3-8. Showing the sampling-positions of bottom fauna

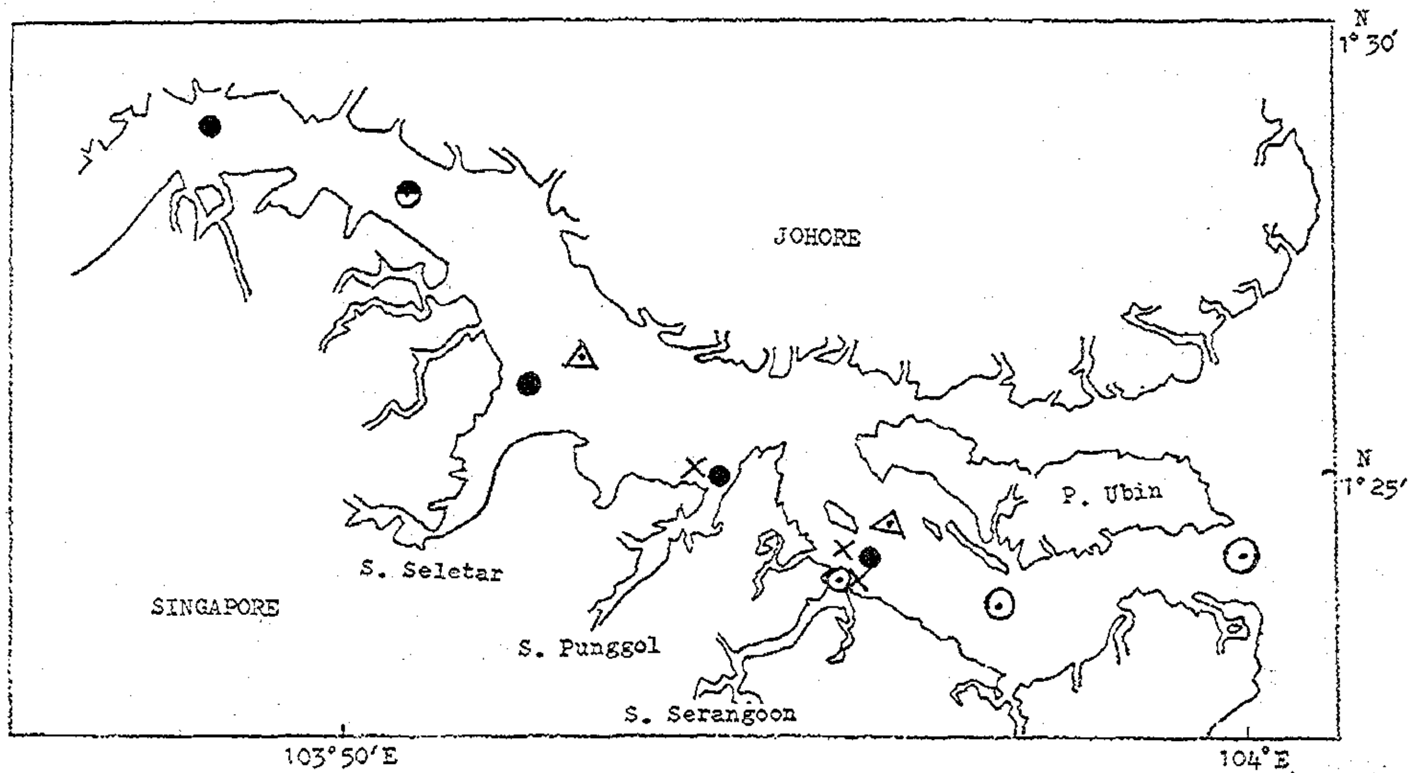

Fig. 3-9. Properties of sediments

○ : Mud, ◓ : Black (Surface) mud, ● : Black mud,
△ : Sandy mud, ✕ : Humus

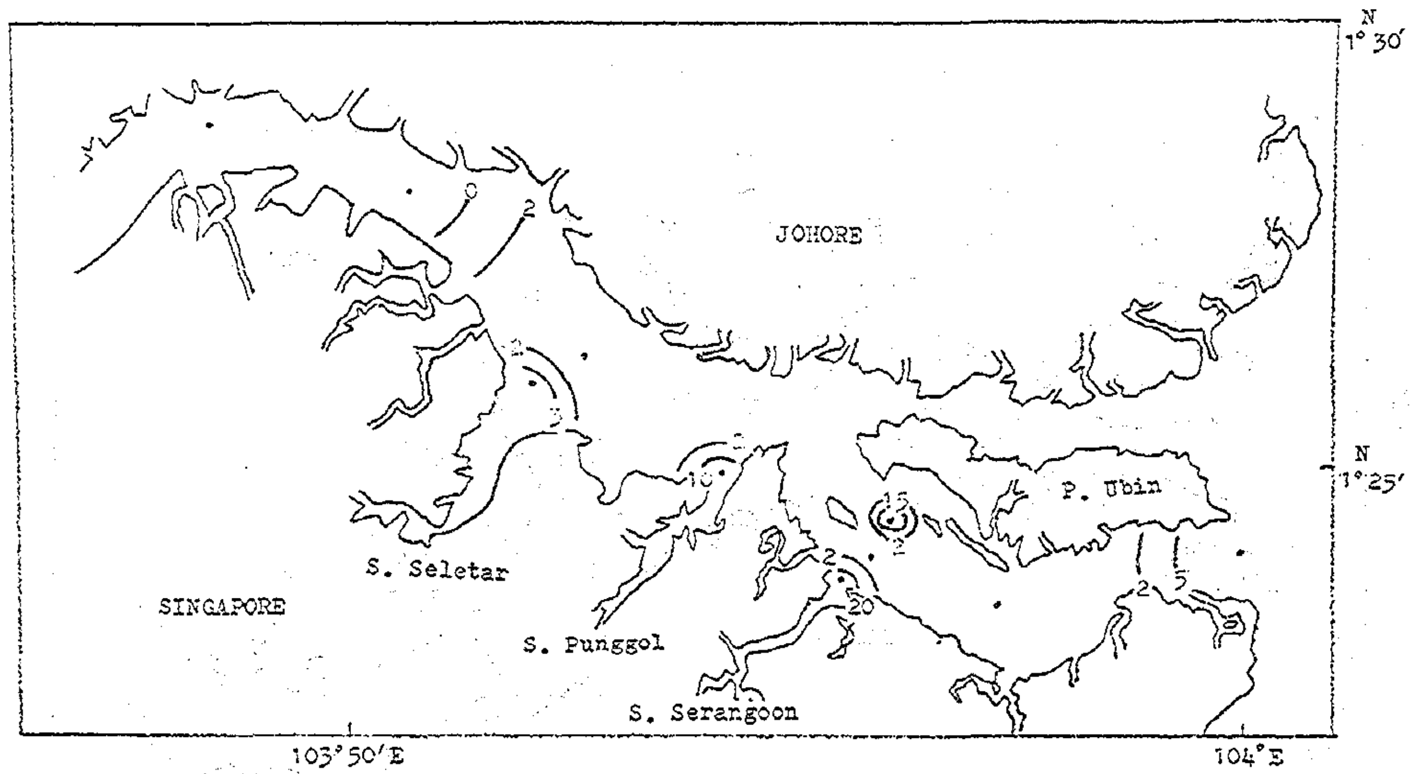

Fig. 3-10. Distribution map of bottom fauna in number of species

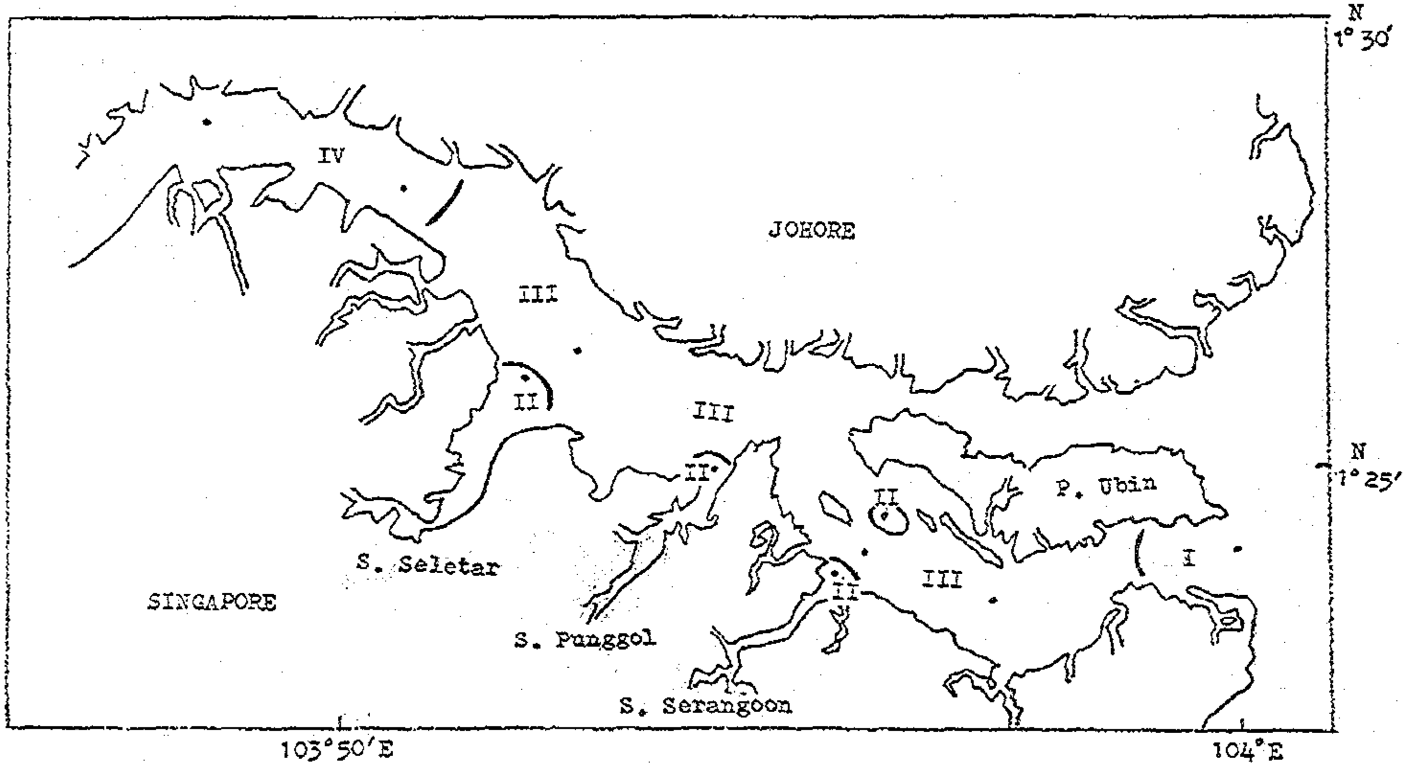

Fig. 3-11. Current status of pollution viewed from benthic communities

I : Healthy region,
II : Eutrophic – Supernutrived region,
III : Polluted region,
IV : Azoic region