Because of the location, the water around this station is affected by the high human activity of large suburb of S. Francisco in Niteroi, and the inflow of highly polluted river running through it.

The water around St. 38 (in Jurujuba) was also polluted, maybe by the effluent from water treatment plant, Planta Tabaiba.

The coastal area of the Rio Porto (St. 40) also had bad water quality. All values of water quality were higher than that obtained at St. 37; COD(Mn) was 12.4 mg/l at the surface, TN was 3.24, TP was 0.70 mg/l and Chl-a was 108.3 ug/l.

DO at St. 40 was, however, 136 % in the surface layer reflecting the high Chl-a concentration, and 17 % on the bottom reflecting the areas bad pollution.

It is obvious the area is effected by many of industries located nearby and traffic of big ships.

TN concentrations at all stations were high, except at Stns. 33 and 35 where it is almost same as those found during the regular survey stations of 8, 9 and 13 in the wet season. However, the ratio of TON to TN is very high even at Stns. 33 and 35 (70 - 100 % of TN).

Results indicate that the water in the inner part of Botafogo, is not seriously polluted yet (St. 33). The outer part of Jurujuba in contrast to the inner part and other areas are also not polluted yet.
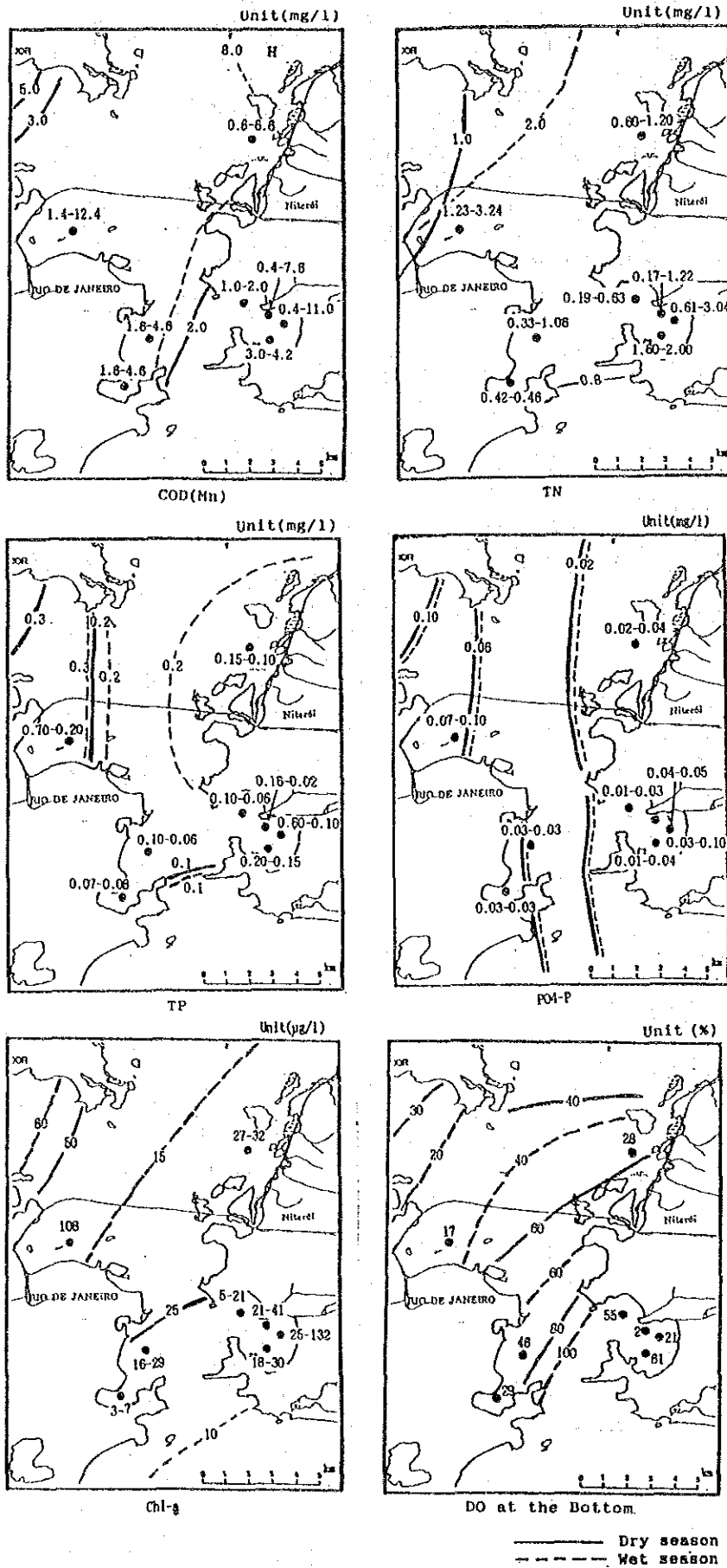
Fig. 2.4-1   Water Quality Conditions in Small Bays and Coastal Areas

CHAPTER 3

SEDIMENT QUALITY

CHAPTER 3

SEDIMENT QUALITY

To understand the contaminated condition of the sediments dis-
tributed in Guanabara Bay, surface sampling was carried out at 15
stations. Chemical analysis was carried out on the core samples
taken from 4 stations.

3.1   Surface Sediment Quality

3.1.1 Methods for Sampling and Analysis

Surface sampling was carried out from June 4 - 6,1992 at 15
stations(station 1 - 18) as showed in Fig.3.1-1.

The Eckman-Birge sampler was used for sampling.

The samples were kept in about 4 degrees centigrade and were
analyzed in the FEEMA laboratory. The items analyzed were water
content, V.S., silt and clay, COD(Cr), KN, TP, T-Cd, T-Pb, T-Cu,
T-Cr, T-Hg, T-Zn, pp'DDT, op'DDE, pp'DDD, PCB's, and CN.

The method of analysis used was "Standard Method for the Examina-
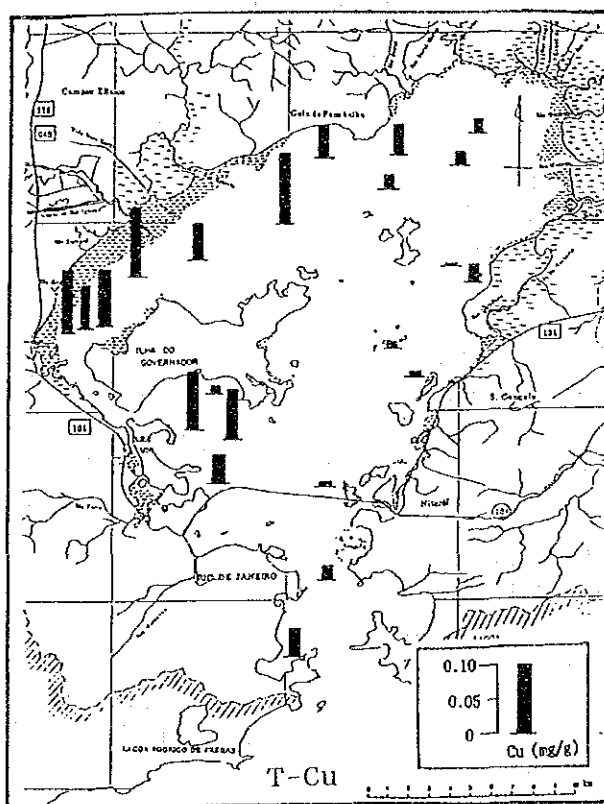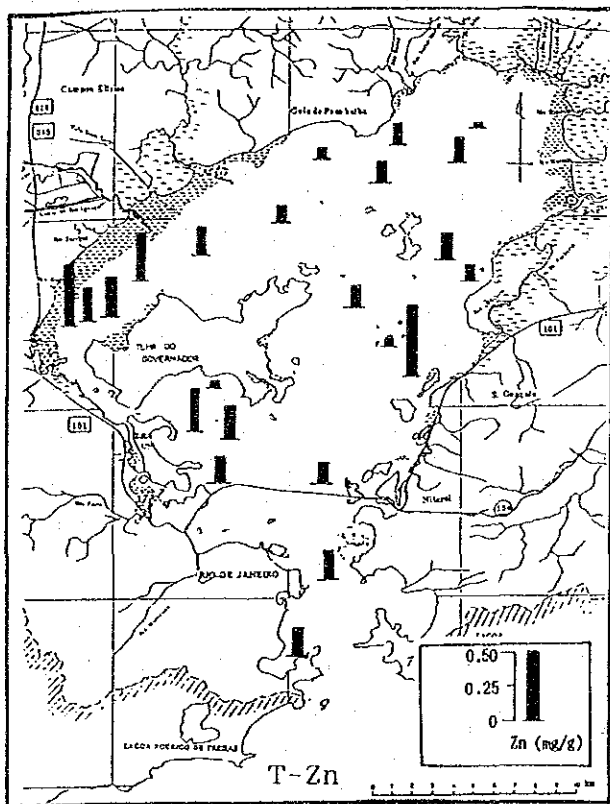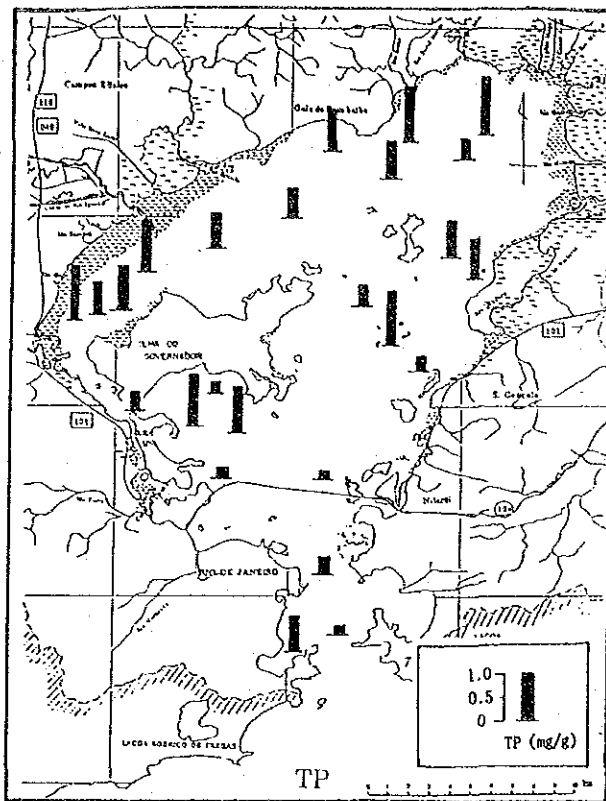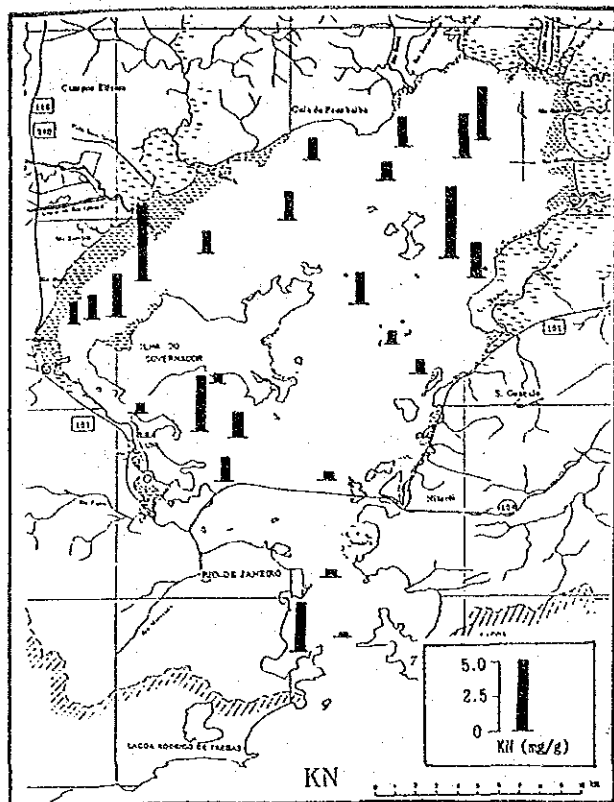tion of Water and Wastewater" in USA.

3.1.2   Results

The results of the analysis on surface sediments are shown in the
Appendix Table APP 3.1-1, and the conditions analyzed in each
item are shown in Fig. 3.1-2(1) - (3).

(1)   Grain Size Distribution (silt and clay)

With the exclusion of station 5 near the Bay mouth and station 8
at the canal on the western side of Governador Island, more than
90% of the make up of the sampled surface sediments is of silt
and clay. The samples from the inner Bay area (St. 13, 14, 15,
16, 17, 18) and the Botafogo small Bay area (St.4) particularly
showed a make up of 99% silt and clay. The silt and clay content
in samples from the central Bay area (St.6, 7, 11, 12) and the
southern side of Governador Island (St.9) was slightly lower at
90 - 97%. The content was particularly low in samples from the
canal on the western side of Governador Island (St.8) and near
the Bay mouth (St.5) at 0 - 39%.

According to the results of tidal observations, areas with high
silt and clay contents are those easily susceptible to current,
While the reverse are those with large flow velocity rates;
particle distribution is thought to be restricted by the flow

Fig. 3.1-1 Bed Surface and Core Sediment Sampling Stations

Silt & Clay and V.S.: Dry weight basis

Dry weight basis

Fig. 3.1-2(1) Distribution of Characteristics of the Surface Sediment

Dry weight basis

Fig. 3.1-2(2) Distribution of Characteristics of the Surface Sediment
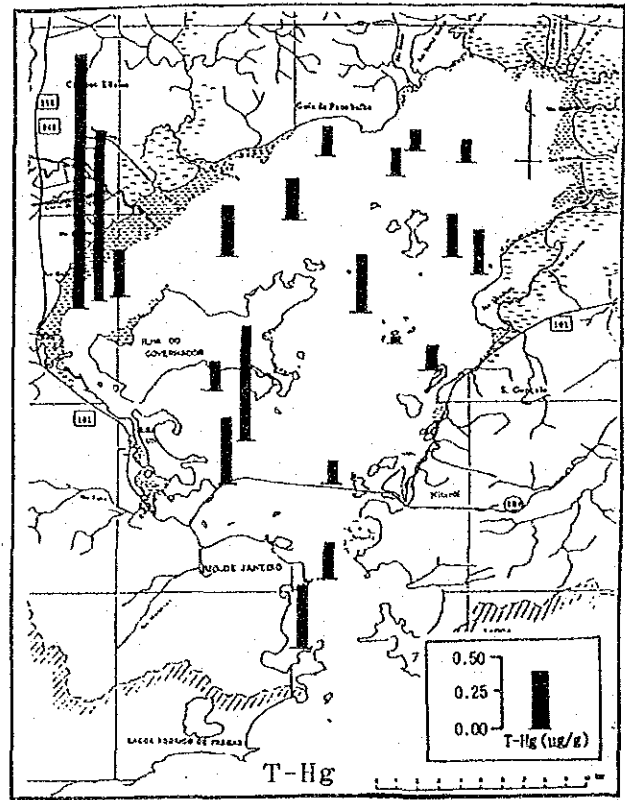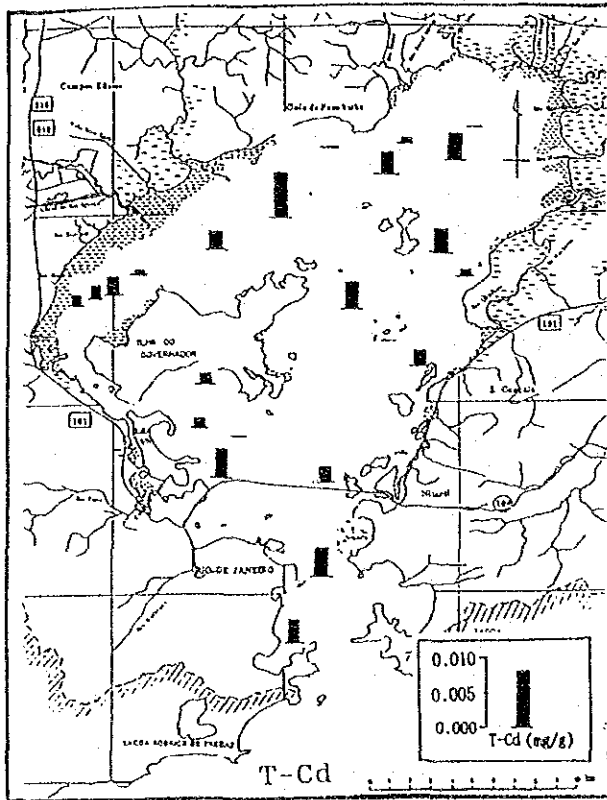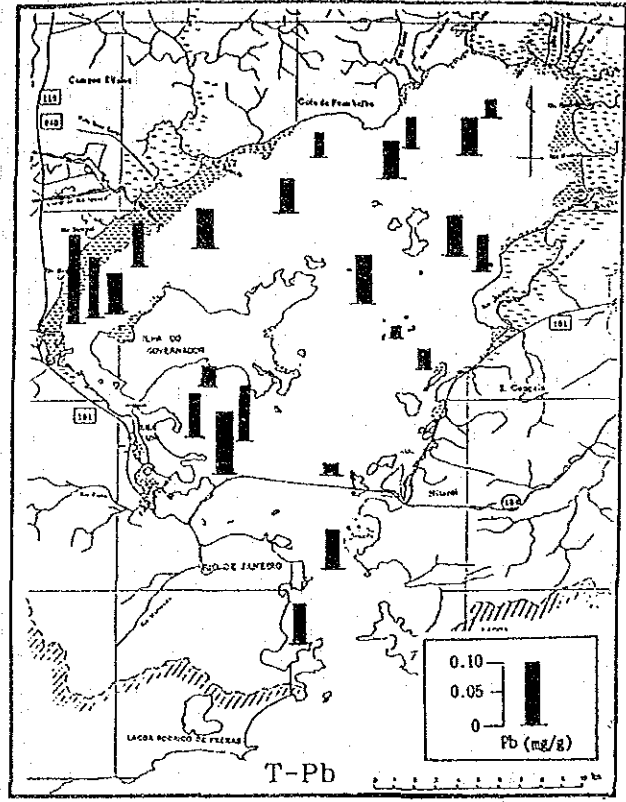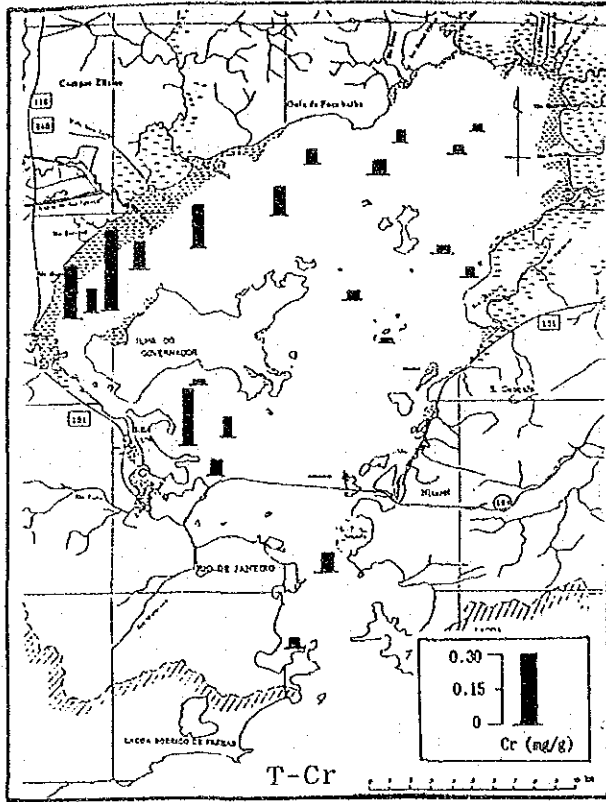
Dry weight basis

Fig. 3.1-2(3) Distribution of Characteristics of the Surface Sediment

velocity in the Bay.

(2)   Water Content

Maximum water content was measured in the surface samples from
the Bay area (St.16) at 83.9%;   the minimum value measured was
23.4% at St.3 at the Bay mouth.

With the exclusion of the western inner Bay area,   the samples
taken from the inner Bay area and the small Botafogo Bay area had
high water contents measuring 77 -84%.   Samples from the western
inner Bay area and the eastern side of Fundao Island showed
slightly lower values at 38 - 77%.   On the other hand, extremely
low values were taken from the central Bay area towards the Bay
mouth and the southern side of Governador Island,   at 23 - 46%.
The water content in the sediment is generally thought to be in
correlation with the sediment particles.

(3)   Volatile Solids (V.S.)

The maximum V.S. content in surface sediments was measured at
St.16 in the eastern inner Bay area at 34.9%,   while minimum was
2.0% at St.13 in the western Bay area.

Regionally, the majority of the inner Bay area,   eastern side of
Fundao Island and the small Botafogo Bay area,   which were found
to have high silt and clay content,   were also observed to have
high V.S.,   at 11 - 35%.   Likewise,   areas with low silt and clay
content (the western inner Bay area,   the canal at the western
side of Governador Island,   and the Bay mouth area) were observed
to have low V.S.,   at 2 - 5%.

Generally, the V.S. content rate in the sediment will be the
standard amount of organic matter present in the sediment, hence
areas with high content of silt and clay are   also considered to
have high content of organic matter.

(4)   Chemical Oxygen Demand (COD(Cr))

The maximum COD(Cr) content in the surface sediments was measured
at St.35 in the western inner Bay area at 227mg/g, while the
minimum was 14.1 mg/g at St.3 in the Bay mouth.

COD(Cr) concentration is high in the inner Bay area,   eastern
side of Fundao Island and the small Botafogo Bay area,   at 58.7 -
227 mg/g.   Concentration was low in the   southern side of Gover-
nador Island and the Bay mouth,   at 14.1 - 58.7 mg/g.

Based on the results of the study on river water quality and
inflowing load,   areas measured to have high COD(Cr) concentra-
tion are also considered to be highly concentrated with the water
quality of inflowing rivers and naturally have large inflowing

load. Conclusively, the particles containing organic matter that flow from the rivers are thought to settle easily in area of near the river mouth and the low flow velocity in the Bay.

(5)   Kjeldahl Nitrogen (KN)

The maximum KN content in the surface sediments was measured in St.35 in the western inner Bay area, at 5.3 mg/g, while the minimum was 0.3 mg/g in St.3 at the Bay mouth.

Concentration was observed to be high in the eastern and western inner Bay areas, the eastern side of Fundao Island and the small Botafogo Bay area, at 1.4 - 5.3 mg/g. Concentration tends to decrease from the central inner Bay area, southern side of the Gobernador Island and the central Bay area toward the Bay mouth at a range of 0.3 - 2.2 mg/g.

(6)   Total Phosphorus (TP)

Maximum TP concentration was observed from samples taken in St.36 in the eastern inner Bay area, at 1.20 mg/g. The minimum was 0.2 mg/g in St.3 and 6 in the Bay mouth area.

TP concentration tends to increase in the inner Bay area, eastern side of Fundao Island and the small Botafogo Bay area at 0.45 - 1.2 mg/g, and tends to decrease from the southern side of Governador Island and the central Bay area towards the Bay mouth at 0.20 - 0.4 mg/g.

(7)   Total Zinc (T-Zn)

Maximum T-Zn concentration was measured in samples taken from St.11 at 0.50 mg/g, and the minimum was from samples taken in St.9 at 0.03 mg/g.

T-Zn concentration tends to increase in the western inner Bay area, eastern side of Fundao Island and the eastern side of the central Bay area, at 0.18 - 0.50 mg/g. Concentration was observed to be low in other areas, at 0.04 - 0.20 mg/g.

(8)   Total Copper (T-Cu)

T-Cu concentration in surface sediments was maximum in St. 18 and minimum in St.15, at 0.100 mg/g and 0.002 mg/g respectively.

T-Cu concentration tends to be higher in the western and central inner Bay areas, the eastern side of Fundao Island and the small Botafogo Bay area, at 0.004 - 0.100 mg/g. Concentration in other area tends to decease, at 0.004 - 0.025 mg/g.

(9)   Total Chromium (T-Cr)

T-Cr concentration in surface sediments was maximum in St. 13 at
0.34 mg/g. The minimum amount is undetected (St. 6 and 11).

Concentration was observed to be high in the western inner Bay
area and the eastern side of Fundao Island at 0.1 - 0.34 mg/g,
and low in other areas at 0 - 0.09 mg/g.

(10)   Total Lead (T-Pb)

T-Pb concentration in surface sediments was maximum in St.22 at
0.14 mg/g and minimum in St.6 and 21 at 0.02 mg/g.

The distribution of T-Pb concentration did not indicate signifi-
cant regional discrepancy, as it was observed to be slightly
higher, at 0.07 - 0.14 mg/g, in the western inner Bay area and
the eastern side of Fundao Island, and only 0.02 - 0.08 mg/g in
other areas.

(11)   Total Cadmium (T-Cd)

T-Cd concentration in surface sediments was maximum in St.18 and
minimum in Stations 6, 9, 11, at 0.007 and 0.002 mg/g respec-
tively.

T-Cd concentration is low in the entire Bay area, hence the ab-
sence of any significant discrepancy. However, the concentra-
tions measured from St.20 - 23 and 35 - 37, which were compara-
tively lower than what was measured from St.3 - 18, are caused by
unknown factors.

(12)   Total Mercury (T-Hg)

T-Hg concentration in surface sediments was maximum in St.22 and
minimum in St.21, at 1.80 and 0.05 µg/g respectively.

T-Hg concentration was very high in the western inner Bay area,
at 0.3 - 1.8 µg/g, followed by the eastern side of Fundao Island
at 0.45 - 0.80 µg/g. Concentration in the eastern inner Bay area
was observed to be less than the western side, at 0.15 - 0.20
µg/g.

(13)   Dichlorodiphenyltrichloroethan (DDT)

DDT is distributed in farmlands as insecticide. It breaks into
its intermediate materials (op'DDE, pp'DDE, pp'DDD) during the
dissolution process. This survey has concluded that the DDT and
its intermediate materials, content in the sediments is lower
the established limit value (<0.1 µg/g).

(14)　　Polychlrinated Biphenyls (PCB's)

PCB's are used as nonconductor and has various isomer. The PCB's concentration in Guanabara Bay measured in this study was less than the established limit value (<0.1 µg/g).

(15)　　Cyanide (CN)

CN is usually found in insecticides, used in metallurgy and chemical electric gilding works, and is extremely toxic. The concentration found in Guanabara Bay was less than the estab- lished limit value (<0.01 mg/g).

3.2　　Vertical Distribution of Sediment Quality

3.2.1　　Method for Sampling and Analysis

Core sampling was carried out at 4 stations in October 26 and 31, as shown in Fig.3.1-1. The sampler used is shown in Fig.3.2-1. Sampling was carried out at depths attainable by manpower. The depths established at each station are as shown below:

Station 23	–	97 cm
Station 24	–	126 cm
Station 25	–	160 cm
Station 26	–	140 cm

The extracted samples were kept under 4 degrees centigrade and analyzed in the laboratory of FEEMA.

The items analyzed were water content, COD(Cr), KN, TP, T-Zn, T-Cu, T-Cr, T-Pb, T-Hg, Fe, Ni, and Mg. The method of analy- sis used was similar to the one mentioned in 3.1 (Surface Sedi- ment).

3.2.2　　Results

The results of the analysis of core sediments are shown in the Appendix Table APP 3.2-2(1) - (4). The concentrations of each analyzed item are shown in Fig.3.2-2(1) - (3).

(1)　　Water Content

The maximum amount of water content in the core sediments is 82.5% (St.25, from 0 - -5cm deep), while the minimum is 50.0% (St.23, from -84 - -94cm deep). With the exclusion of St.26, water content decreases with depth, a phenomenon attributed to the pressurized extraction of pore water. Water content in the surface layer of St.26 decreases (57.2%), but in further depths,
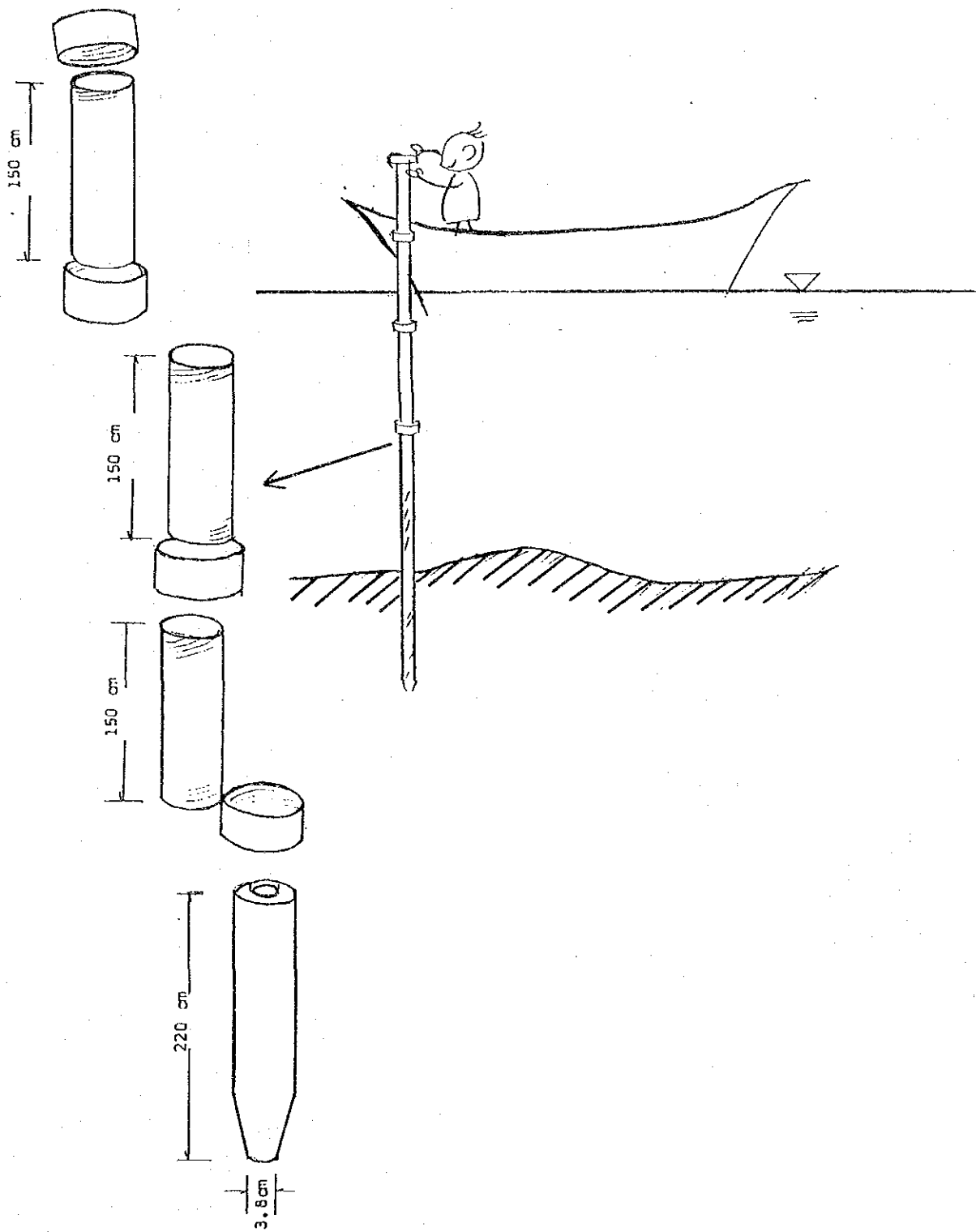
Fig. 3.2-1   Core Sampler

Dry weight basis
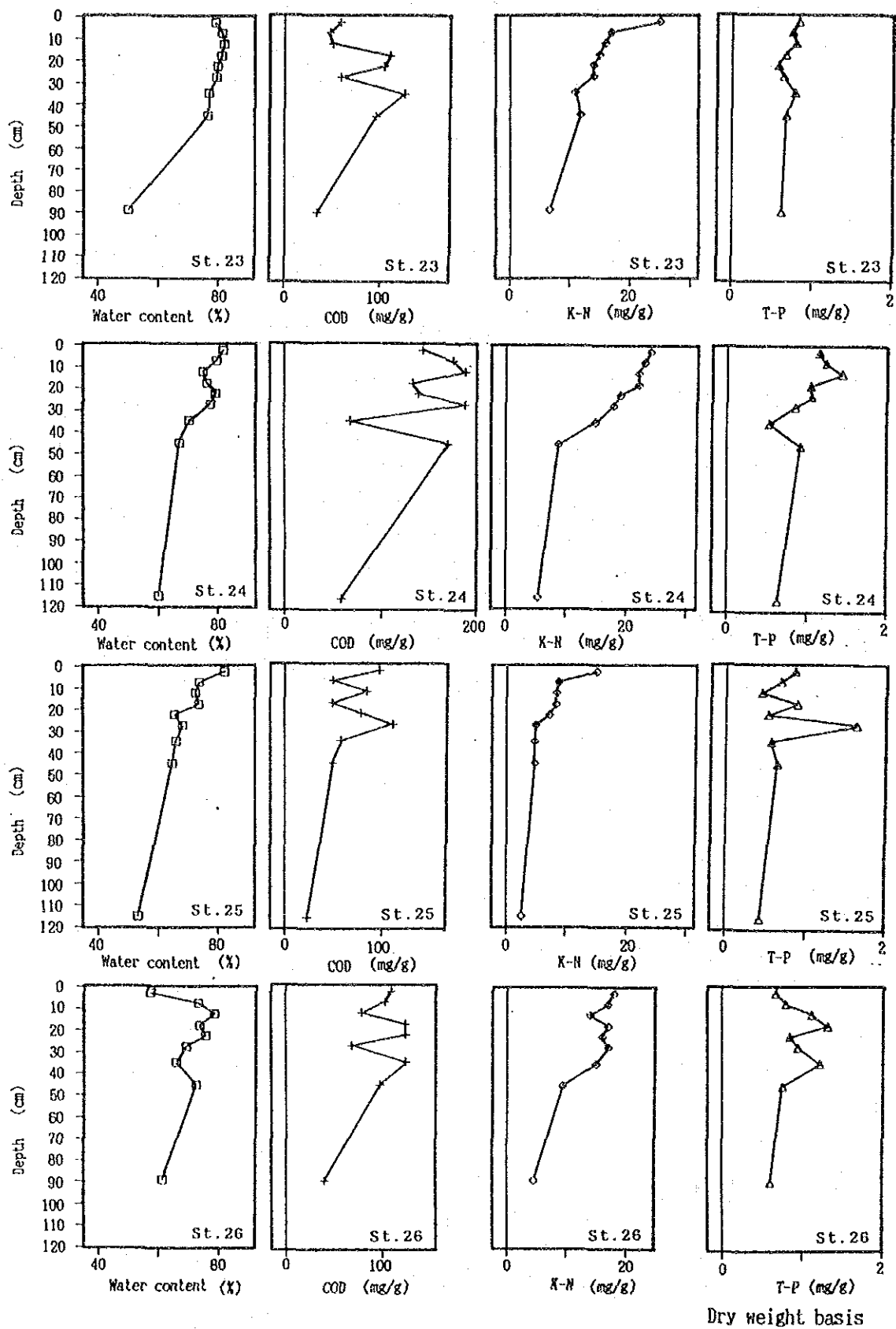
Fig. 3.2-2(1) Vertical Change of Characteristics in the Core Samples

changes and is usually low in the entire Bay area. However, concentration increases in St.26, in layers below the sea bed shallower than -50cm.

(6) Total Copper (T-Cu)

The maximum amount of T-Cu in the core sediments is 0.120 mg/g (St.26, 15 - 30cm deep), and the minimum is 0.006 mg/g (St.25, -20 - -25cm deep).

With the exception of St.26, the changes in the perpendicular direction of T-Cu is slightly high in the surface layer, but low in the entire Bay area. In St.26, concentration particularly increases in layers in the sea bed which are shallower than -50cm.

(7) Total Chromium (T-Cr)

The maximum amount of T-Cr in the core sediments is 0.28 mg/g (St.26, -25 - -30cm deep), and the minimum is 0.04 mg/g (in numerous stations).

With the exception of St.26, the perpendicular direction of T-Cr concentration slightly changes and is low in the entire basin area. It is however observed to increase significantly in sea bed layers shallower than -50cm.

(8) Total Lead (T-Pb)

The maximum amount of T-Pb in core sediments was 0.18 mg/g (St.26, -15 - -20cm deep). T-Pb was not extracted from numerous stations.

T-Pb concentration is high in sea bed layers shallower than -50cm, in St.26. It particularly increases in the sea bed layer (-15 - -20cm) of St.24; the cause is unknown. Changes in the perpendicular direction of T-Pb in St.23 and 25 were not observed, however, concentration is low in the entire Bay area.

(11) Iron (Fe)

Fe concentration was not observed to undergo changes in its perpendicular direction in any station.

(12) Nickel (Ni)

Ni was slightly higher in St.26, from 0 - -50cm. Changes in perpendicular direction were not observed in other stations.

3-11

the amount is similar to the amount measured in other stations.

(2)   Chemical Oxygen Demand (COD(Cr))

The maximum amount of COD(Cr) found in the core sediments was 189
mg/g (St.24, -10 - -15cm deep), while the minimum amount is 35
mg/g (St.23, -84 - -94cm deep).

In all stations, from 0 - -50cm deep, COD(Cr) concentration is
observed to be high in spite of fluctuations, and low in further
depths.

The survey on sediment settling velocity indicates that velocity
in areas shallower than -20 - -50cm is 7 times more the velocity
in deeper areas.   Areas with high velocity and high COD(Cr)
concentration are found to be the same.

(3)   Kjeldahl Nitrogen (KN)

The maximum KN amount in core sediments is 2.5 mg/g (St.23, 0 -
-5cm deep), and the minimum is 0.13 mg/g (St.25, -110 - -120cm
deep).

KN concentration is observed to decrease with depth at all sta-
tions. The changing tendencies prevalent to this water property
is similar to that of water content. However, due to the pres-
surized attraction of pore water, this property reduces NH_4-N.

KN concentration in areas shallower than -50cm is higher than in
deeper areas. The reasons behind this are similar to those af-
fecting COD(Cr) concentration.

(4)   Total Phosphorus (TP)

The maximum amount of TP in core sediments is 1.64 mg/g (St.25,
-25 - -30cm deep), and the minimum is 0.43 mg/g.

The changes in the perpendicular direction of TP show trends
similar to that of COD(Cr). From the basin, both properties
mostly flow in the from of particles and show the same behavior
patterns before settling.

(5)   Total Zinc (T-Zn)

The maximum amount of T-Zn in core sediments is 0.65 mg/g (St.26,
-15 - - 20cm deep); there were also areas where T-Zn was not
measured (St.25, -110 - -120cm deep).
The perpendicular direction of T-Zn in core sediments is 0.65
mg/g (St.25, -110 - -120cm deep).

The perpendicular direction of T-Zn concentration slightly
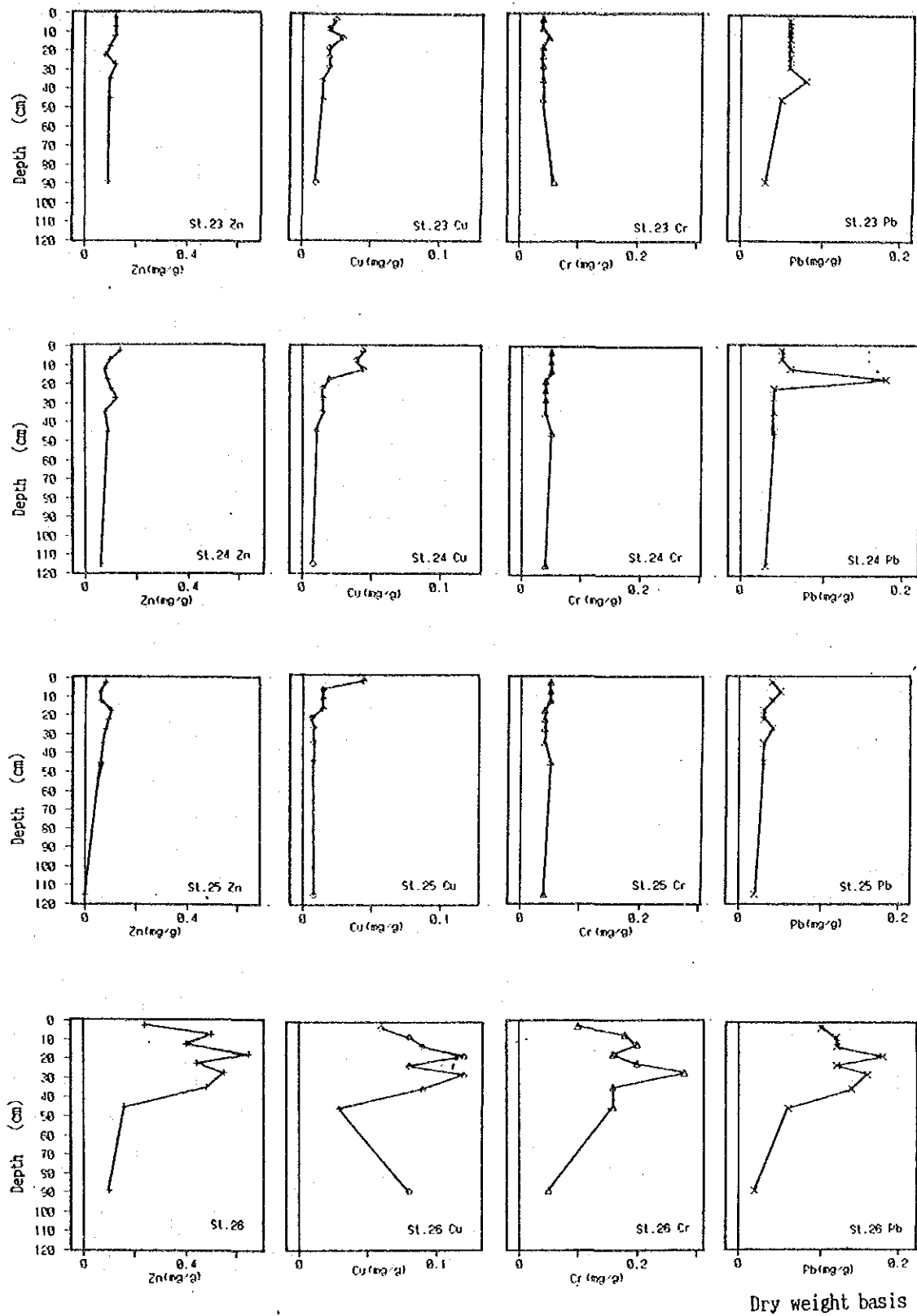
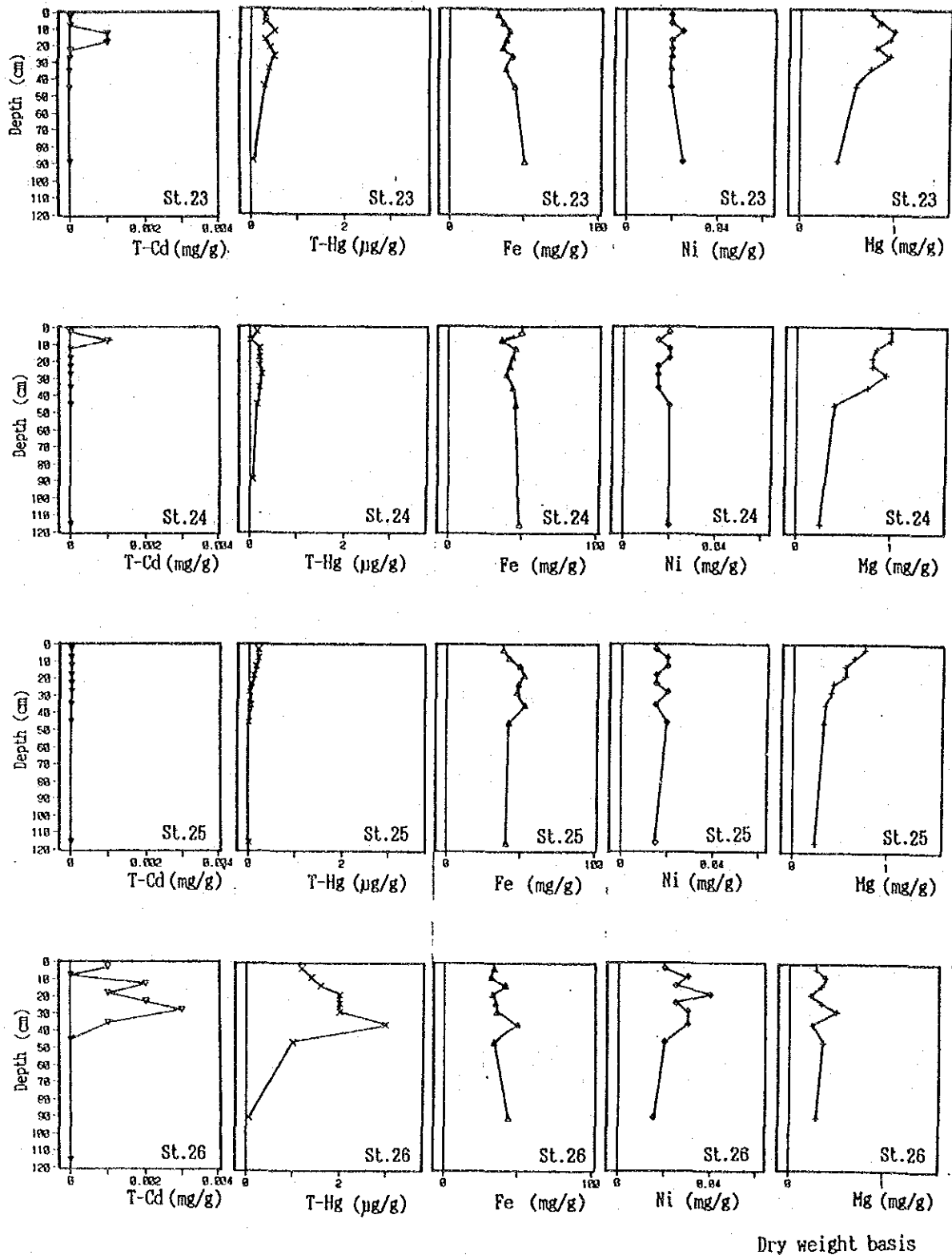Fig. 3.2-2(2)· Vertical Change of Characteristics in the Core Samples

Dry weight basis

Fig. 3.2-2(3) Vertical Change of Characteristics in the Core Samples

3.3   Discussion

The silt and clay contents of the sampled surface sediments, water content, VS, COD(Cr), KN, TP contents as well, are highly concentrated in the inner Bay, eastern side of Fundao Island and the small Bay area of Botafogo, while concentrations tended to decrease on the southern side of Governador island, the central Bay area and near the Bay mouth.

The areas where the values of the above parameters were high almost coincided with: the mouth areas of rivers with large pollution loads and the areas where the upper layer has high organic and nutrient concentrations and is low in flow velocity. Secondary pollution caused by internal production accelerates sediment contamination in these areas.

On the other hand, the areas (central Bay area and Bay mouth area) where the values were low were those far from the mouths of rivers and were observed to have upper layers with low organic and nutrient concentrations and high flow velocities.

Concentration of organic material and nutrients in the sediment is considered to be strongly controlled by the distance from the river mouth, concentration in the upper layer, and flow velocity and direction in the Bay. However, the areas observed to have low values of the above parameters (near the canal at the southern side of Governador Island, and near St. 11 in the eastern Bay area) were identified as areas near the mouths of rivers with large pollution loads, upper layers with high organic content and concentrations and high flow velocity. It was concluded that, flow velocity affects the formation a lot more than the other factors mentioned.

Heavy metal concentrations in surface sediments, with the exception of T-Cd, were observed to be high in the western inner Bay area and on the eastern side of Fundao Island, but inclined to decrease towards the central Bay area and the Bay mouth.

According to the results of a study on the source of pollution in the Guanabara Bay Basin, the inflow from the basins of the Sarapui and Iguacu rivers into the western inner Bay area contained Zn, Cr, Cu and Pb discharged by factories. Further, a river water quality survey conducted by FEEMA from 1980 to 1986 indicated high concentrations of Cr and Hg in the inflow of the Sarapui and Sao Juan de Meriti rivers to the same area. However, the same survey repeated in 1987 - 1989 showed reduced levels of concentrations. The concentrations of these metals were observed to be also low during the river survey conducted in this study.

Conclusively, heavy metal concentrations detected before 1986 are thought to have accumulated near the river mouth east of Fundao Island and in the western inner Bay area.

With the exclusion of Station 23, the vertical changes of concentrations of COD(Cr) and TP indicated similar tendencies,

which were observed to be higher between 0 and -50 cm than below -50.

This is attributed to the fact that the majority of the COD (Cr) and TP flow in particle form; both elements have similar sedimentation behavioral patterns.

Water content and KN concentration at each station decreased with depth similarly mainly due to the compaction of pore water.

The T-Zn, T-Cu, T-Cr, T-Pb, T-Cd and T-Hg concentrations at Station 26, which is located in the western inner Bay area, were considerably higher than at other stations. The change in their vertical distributions are low near the surface layer, higher from -10 to -30 cm, and lower further down. This condition suggests the discharge of heavy metals, mainly prior to 1986 as referred to in 5.4.1. Due to the reduced discharge of heavy metals in recent years, their concentration in the surface layer has decreased.

Sedimentation rate in the inner Bay area was observed to be approximately 7 times faster in layers shallower than -20 to -50cm than in deeper layers.

The areas observed to have high COD(Cr), KN and heavy metal concentrations coincided with areas observed to have fast sedimentation rates, which can be attributed to the voluminous discharge of pollutants when industrial activities were thriving and development in the catchment area was at peak.

According to the results of this study, T-Hg in surface and core sediments was high in the western inner Bay area at 3.00 ug/g but about 1/8 of the Japanese Standard value for river and lake sediments (25 mg/kg). On the other hand, FEEMA's survey (1980 - 1986) showed a high concentration (4.79 µg/g), 1/5 of the established Japanese Standard value.

Although this study has not measured the PCB's concentration, FEEMA, in 1989, measured 100 ug/kg of PCB's, an amount which is 1/100 of the PCB's standard value set for the Japanese sea area (10 mg/kg).

The studies about concentrating of heavy metals and chemical matters in aquatic organisms were performed by the RJFV, FEEMA and IBMA, and the results show that heavy metal concentration in mussels is 4 times larger than the normal concentration, Cu and Zn concentrations in shrimps and crabs are high, and Hg concentration is high in catfish (0.45 µg/g). All values obtained were found to be below the OMS allowable limit of the U.S FOOD AND DRUG ADMINISTRATION.

Consequently, sediment contamination through the food chain is presently not affecting humans.

Surveys regarding sediment, however, is necessary to be continued

for monitoring to prevent future problems.

1). Concentrations of heavy metals and chemical substances should be measured at the places near the mouth of the rivers with large flowing loads, especially on the west side of the Bay.

2). It will be necessary to monitor the concentrations of heavy metals and chemical substances in edible fish and shell-fish, in particular for the species which highly concentrate of these substances in their bodies.

3). It is also necessary to measure release rate of the several parameters which are COD(Mn), BOD, TN, NH_4-N, TP, PO_4-P and heavy metals in river mouth areas with large flowing loads.

CHAPTER 4

MEASUREMENTS AND EXPERIMENTS
FOR UNDERSTANDING OF THE
MATERIAL CYCLE IN THE BAY

CHAPTER 4

MEASUREMENT AND EXPERIMENT FOR UNDERSTANDING OF THE MATERIAL CYCLE IN THE BAY

4.1 Primary Productivity Measurement

When organic pollution mechanism in the Bay is considered, the direct pollution introduced inflwoing organic materials through the rivers and internal production (secondary organic pollution) caused by eutrophication should be taken into account.

The eutrophication has been accelerated chiefly by changing environmental conditions surrounding the Bay have increased the flow of nutrients. Internal production increases with accelerated eutrophication.

Internal production (primary production) was measured as an indicator of eutrophication in the Bay. The results were used to determine the material cycle or material balance, and the pollution mechanism in the Bay.

The phyotplankton species composition, euryhaline in the inner Bay, and its physiological condition results different levels of productivity in different areas of the Bay.

Primary productivity measurements were carried out <u>in situ</u> in November, 1992 and in April and May, 1993.

4.1.1. Primary Productivity Measurement-1

Primary productivity measurement-1 was performed on November 23,25 and 26 (wet season) at 6 stations. These stations were selected to represent different sub-areas according to their water pollution (Fig. 4.1-1).

Clear and dark oxygen bottles were used during the measurement <u>in situ</u>; water samples were collected at 0.1 m, at the Secchi-disk reading depth and at the depth where the light intensity was 1 % of that at the surface. The depth with 1 % light intensity is generally considered to be present at the bottom of the euphotic layer.

Clear and dark oxygen bottles were filled up with water sampled from each depth, then hung and left at their original depths for basically 2 hours from 11:00 (Fig. 4.1-2).

The respiration rate measurement was dune using the dark bottles with the same method as the clear bottles.

Net primary per unit area was calculated by integrating DO production from the surface to the euphotic layer: the depth with

Fig. 4.1-2   Scheme for Primary Productivity
Measurement

Fig. 4.1-1   Stations for Primary Productivity
Measurement-1 (St. 27 - St. 32) and
Measurement-2 (St. 50 - St. 55)

1% of the surface light intensity.

Productivity per day was estimated for 12 hours.

Measured DO production was converted to carbon using the factor of 0.28 according to stoichiometric formula for photosynthesis and respiration of phytoplankton.

At Stns. 30 and 32, the depth of the euphotic layer were corrected from 2.8 m and 4.0 m, which were the depths with 1% surface light intensity, to 2.3 m and 3.4 m, the depth was obtained from values extrapolated at the surface and at the Secchi-disk depth. Because of the irregular DO values observed at these depths.

4.1.2   Result of the Measurement-1

Profiles of productivity, respiration rate and Chl-a concentrations at each depth are shown in Fig. 4.1-3 and Tables APP 4.1-1 and 2.

Productivity per unit Chl-a per unit water volume at the Secchi-disk depth at station altered with depth, and was from one third to three quarters in the value at the surface, except at St. 29 where it was only one tenth of the surface value.

Net productivity per unit area a day (total production within the euphotic layer per unit area a day) and productivity per unit Chl-a in the surface layer at St. 28 were a lot smaller than at other stations in spite of the higher Chl-a, extremely high on some occasions, usually observed around this area. This was mainly because light intensity was very weak during the survey (300 lux in the surface layer) and the shallow depth (about 3m) (Fig. 4.1-4 and Table 4.1-1).

Net production at each station per unit area per day was slightly different from the production per unit Chl-a due to differences in water quality, photosynthetic potential of phytoplankton population, euphotic depth, etc.

Productivity obtained in Botafogo Bay during the period from May to July in 1978 ranged from 0.807 to 3.647 mg C/m^2/day (in Bull. Mus. nain. Hist. nat., Paris, 4 ser., 1, 1979). It does not seem there is a significant difference between these values and the values obtained by our measurements of 2.868 mg C/m^2/12h.

Similar respiration rates per unit Chl-a at the three depth were observed at each station, which is the same results as was obtained theoretically.

The ratio of the respiration rate to productivity differed at each station and depth, particularly at 1 % light intensity depth. These ratios were from 21 to 40 % in the surface layer, from 26 to 161 % at the Secchi-disk depth and from 121 to 1240 %

Respiration Productivity
(mg C/mg Chl-a/h)
5.0 0 5.0 10.0 15.0
Chl-a
12:15-14:15
St. 27
(m)
Depth
0 20 40
Chl-a(mg/m³)

Respiration Productivity
(mg C/mg Chl-a/h)
5.0 0 5.0 10.0
Chl-a
15:15-17:15
St. 28
(m)
Depth
0 20 40
Chl-a(mg/m³)

Respiration Productivity
(mg C/mg Chl-a/h)
5.0 0 5.0 10.0 15.0
Chl-a
11:07-13:07
St. 29
(m)
Depth
0 20 40
Chl-a(mg/m³)

Respiration Productivity
(mg C/mg Chl-a/h)
5.0 0 5.0 10.0
Chl-a
11:30-13:30
St. 30
(m)
Depth
0 20 40
Chl-a(mg/m³)

Respiration Productivity
(mg C/mg Chl-a/h)
5.0 0 5.0 10.0 15.0
Chl-a
10:30 -12:30
St. 31
(m)
Depth
0 20 40 80
Chl-a(mg/m³)

Respiration Productivity
(mg C/mg Chl-a/h)
5.0 0 5.0 10.0
Chl-a
11:10-13:10
St. 32
(m)
Depth
0 20 40
Chl-a(mg/m³)

Fig. 4.1-3   Productivity, Respiration Rate and Chl-a at each Depth
(Measurement-1)

Fig. 4.1-4   Net Productivity of Measurements 1 and 2

Table 4.1-1   Net Productivity and Respiration Rate Measurement-1

St.	Productivity (gc/m2/12h)	Respiration (gc/m2/12h)	Respiration (%)	Productivity (mg C/mg Chl-a/12h)	Respiration (mg C/mg Chl-a/12h)	Respiration (%)
St. 27	4.044	2.268	56	163.1	94.2	58
St. 28	1.992	1.044	52	58.0	31.0	53
St. 29	4.104	2.091	51	123.4	95.1	77
St. 30	5.041	2.604	52	121.9	52.2	43
St. 31	8.208	2.223	27	372.2	111.8	30
St. 32	2.868	1.872	65	137.4	110.4	80

Table 4.1-2   Net Productivity and Respiration Rate Measurement-2

St.	Productivity (gc/m2/12h)	Respiration (gc/m2/12h)	Respiration (%)	Productivity (mg C/mg Chl-a/12h)
St. 50	4.824	-	-	272.3
St. 51	5.625	2.087	37	191.1
St. 52	4.150	-	-	102.6
St. 53	6.225	-	-	36.2
St. 54	9.408	-	-	125.6
St. 55	4.650	-	-	-

at the depths with 1 % light intensity, due to the interference of heterotorophic bacterial activities, as well as endogenous respiration of algae (Table 4.1-1).

Respiration rate per unit Chl-$\underline{a}$ within the euphotic layer ranged from 30 to 80 % of the net productivity (Table 4.1-1). The respiration at night is generally known to be about one third of the net productivity during the daytime ("Marine Plankton", 1974). The total respiration a day, therefore, was 60 to 110 % of the productivity per day. These respiration rats seems to be too high to sustain the productivity level.

No significant relation between the carbon produced (or DO) per unit Chl-$\underline{a}$ per unit time and light intensity was found. This may be caused by the mixed phytoplankton population, and because the range of the light intensity used for measurements was not enough to obtain a relationship.

4.1.3   Primary Productivity Measurement-2

Primary productivity measurement was performed again on April 15, 20, 29 and 30, May 12 and 21, 1993 by the staff at the FEEMA laboratory. Although it was hard to carry out all these measurements on sunny days, the staff endeavored to do so whenever it was possible.

Stations 52 (St.27), 54 (St.29) and 55 (St.32) were the same stations used in measurement-1, and the results of the measurements on sunny and cloudy days were expected to be comparable (Fig.4.1-1).

The method of the measurement used was the same as in measurement-1. However, three incubations for each measurement were used this time from 6:00 to 13:00, each incubation time was basically two hours, in order to obtain time course photosynthesis.

Substituted, for the Secchi-disk depths, were with 10 % light intensity of that at the surface. Based on the results of previous work, this depth was considered to be almost equivalent to the Secchi-disk depth.

Net productivity was determined by integrating production/depth, from the surface layer to the depth with 1 % light intensity, and production obtained from the beginning upto the end period of each incubation time, Then productivity per hour was estimated. The productivity per day was determined by multiplying this value by 12 hours.

4.1.4   Result of Measurement-2

Productivity per unit Chl-$\underline{a}$ per unit time (hour) at 0.1 m depth at St. 50 was much higher than other stations (Fig. 4.1-5 and

Respiration   Productivity
(mg C/mg Chl-a/h)

10.0   5.0   0   5.0   10.0   50.0   55.0

1

2

3
                                            06:00-12:00
4
(m)   St. 50-1
Depth

Chl-a

0   20
Chl-a(mg/m³)

Respiration   Productivity
(mg C/mg Chl-a/h)

10.0   5.0   0   20.0   25.0   30.0   45.0   50.0

Chl-a

2
(m)   12:00-13:00
Depth   St. 50-3

0   20   40
Chl-a(mg/m³)

Respiration   Productivity
(mg C/mg Chl-a/h)

5.0   0   5.0   10.0   30.0   35.0

1

2   Chl-a

3
                                    06:00-09:00
4
(m)   St. 51-1
Depth

0   20   40
Chl-a(mg/m³)

Respiration   Productivity
(mg C/mg Chl-a/h)

30.0 25.0 20.0 15.0 10.0 5.0   0   5.0   10.0

1

2

3   Chl-a

4   09:00-11:00
5
(m)   St. 51-2
Depth

0   20   40   50
Chl-a(mg/m³)

Respiration   Productivity
(mg C/mg Chl-a/h)

5.0   0   5.0   10.0   15.0

1

2   Chl-a

3

4

5   11:00-13:00
(m)   St. 51-3
Depth

0   20   40   60   80
Chl-a(mg/m³)

Fig. 4.1-5(1)   Productivity, Respiration Rate and Chl-a
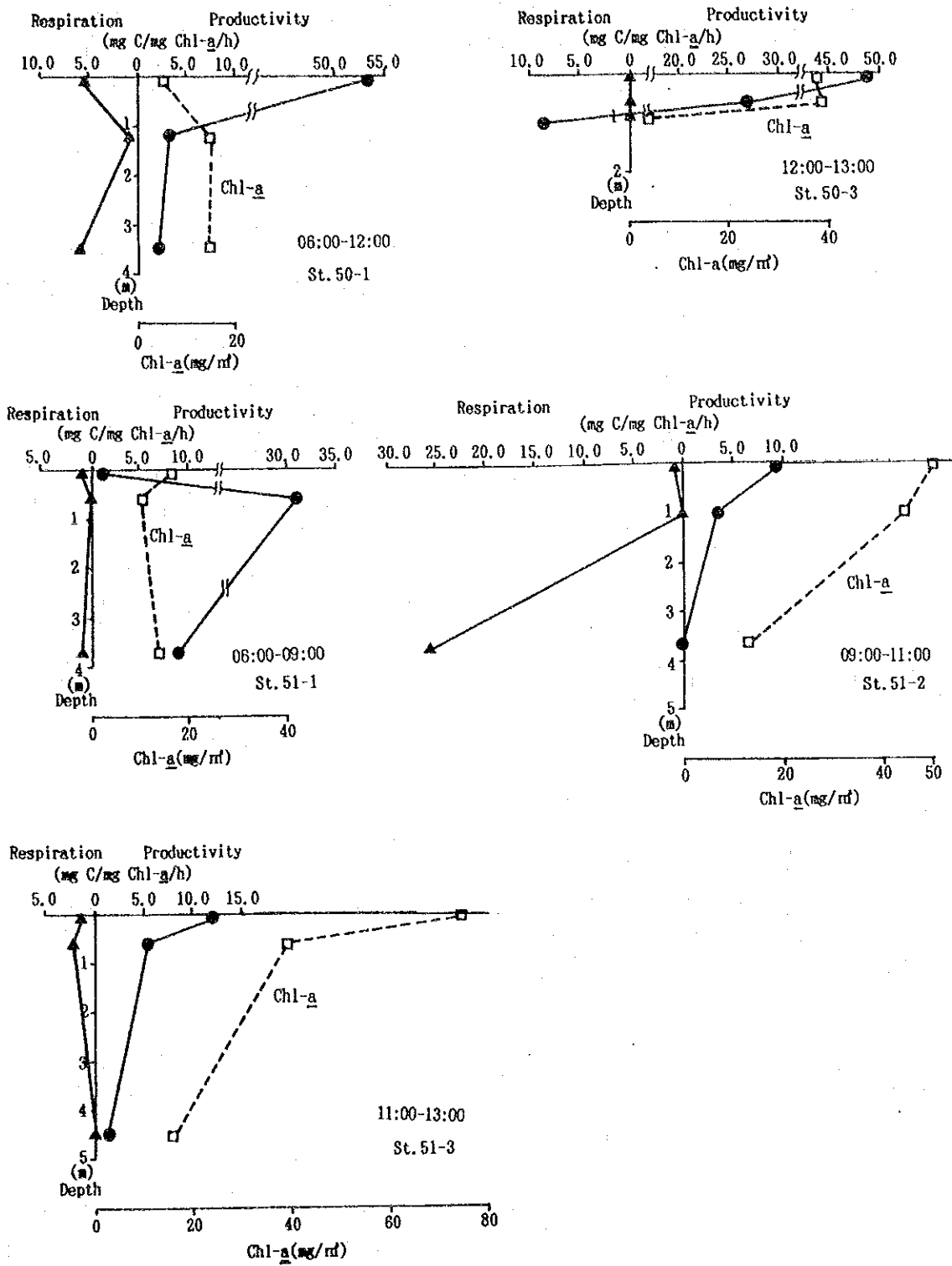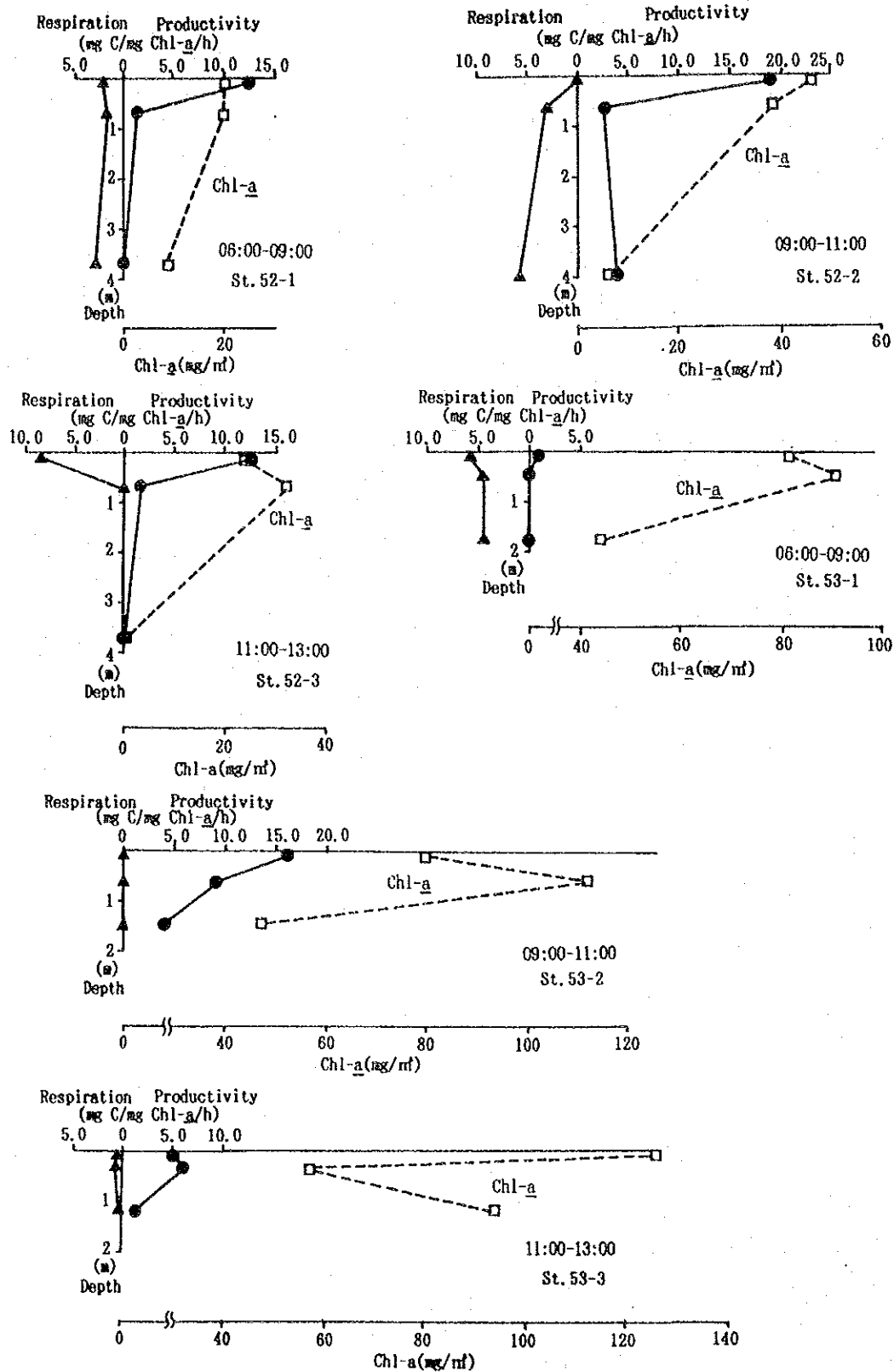at each Depth (Measurement-2)

4-7

Fig. 4.1-5(2)   Productivity, Respiration Rate and Chl-a
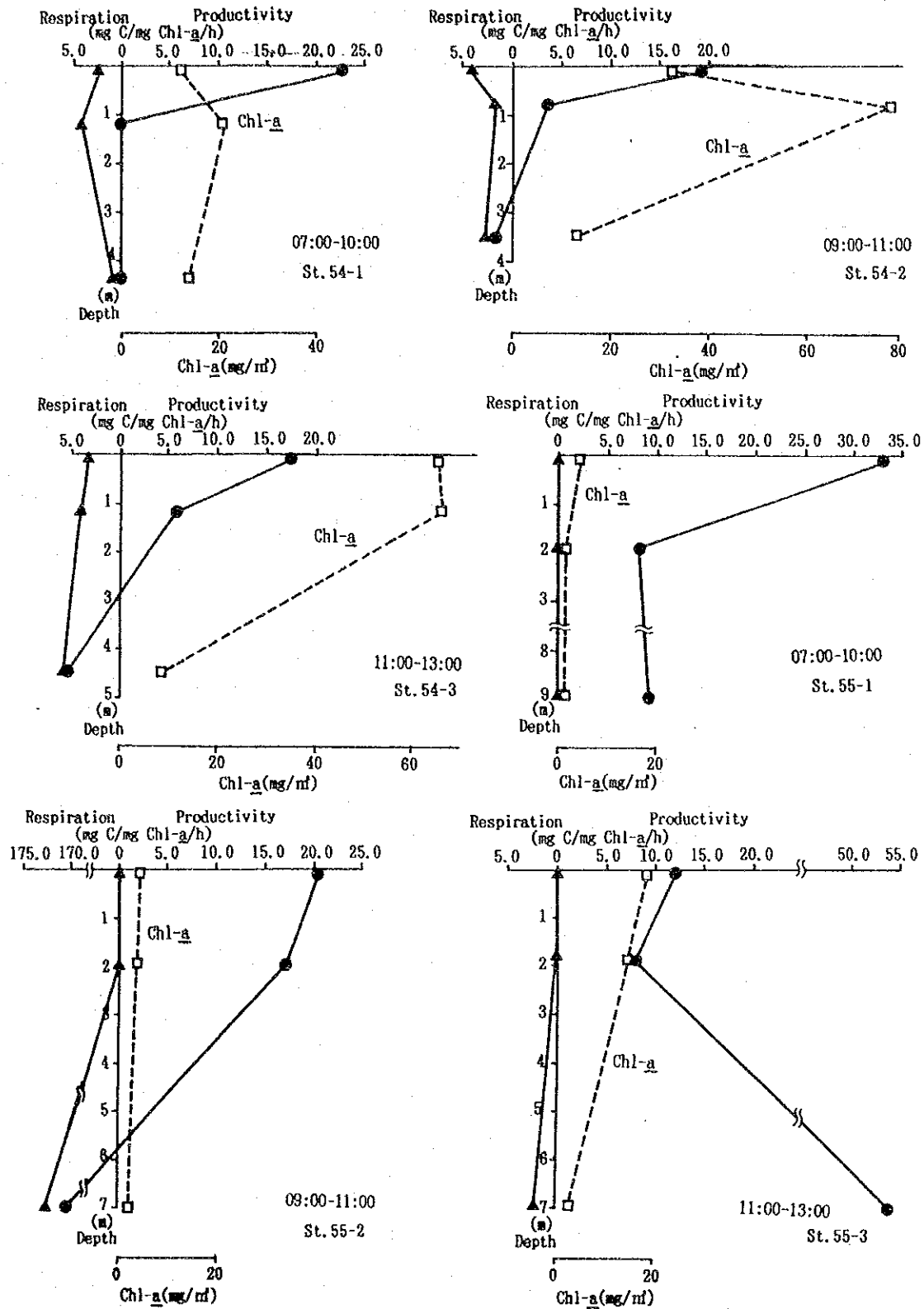at each Depth (Measurement-2)

Fig. 4.1-5(3)   Productivity, Respiration Rate and Chl-a
at each Depth (Measurement-2)

Tables APP 4.1-3 and APP 4.1-4), obtaining lower values at depths with 10 % and 1 % light intensity is due principally to shade effects produced by concentrated algae formation in the surface layer promoted by mass stagnation that occurred frequently around this sampling station.

Unexpectedly, low productivity per unit Chl-a was obtained at St. 53 at all measured depths, in spite of quite high productivity per unit area under high light intensity. Around this station, high Chl-a concentration and also very high phytoplankton numbers were obtained. It can be possibly deduced that high Chl-a caused low productivity per unit Chl-a.

The net production measured in measurements 1 and 2 at similar stations generally corresponded well, except the productivity per unit area at Stns. 54 and 55 (measurement-2) where about twice those found at stns. 29 and 32 (measurement-1)(Fig. 4.1-4, Table 4.1-2). It is thought that the higher light intensity and deeper euphotic depths at Stns. 54 and 55 results in the higher values.

Although the result of respiration was obtained at few stations the ratio to production was wide ranging even at a depth of 0.1 m, which is different from the results measured in measurement-1 (Table APP 4.1-4).

Further measurements of primary productivity under other conditions will give more detailed information on optimum productivity. It is also necessary to measure the relation between light intensity and photosynthesis in order to better understand nature of productivity in each area.

Respiration rate is also very important in estimating the gross internal production in the Bay.

To compare the above values with accepted values; 8.0 mgC/mg Chl-a/h is the value for tropical Pacific and 3.0-4.0 mgC/mg Chl-a/h for tropical Atlantic, under optimum light intensity conditions (Marine Phytoplanktpon). And for shallow sea area 1 gC/m^2/day(Marine Biochemistry).

4.2 Release Rate from Sediment

Laboratory experiments were carried out, 3 points both in Phase 2 and 3, to grasp the amount of organic matter, oxygen and phosphorus released from the sediments in Guanabara Bay.

4.2.1 Experimental apparatus and Theory

The experimental apparatus used was the consecutive storage of water in reaction bottles, as shown in Fig. 4.2-1(1). The theory and results derived from the analysis are as indicated below.
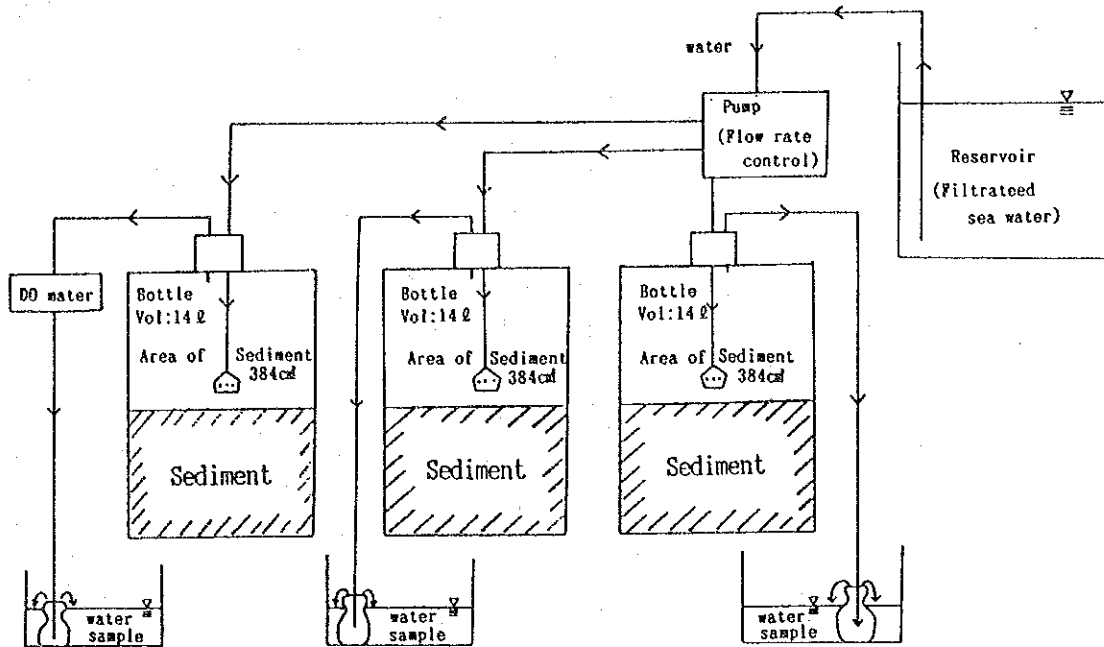
Fig. 4.2-1(1) Experimental Apparatus for Release and
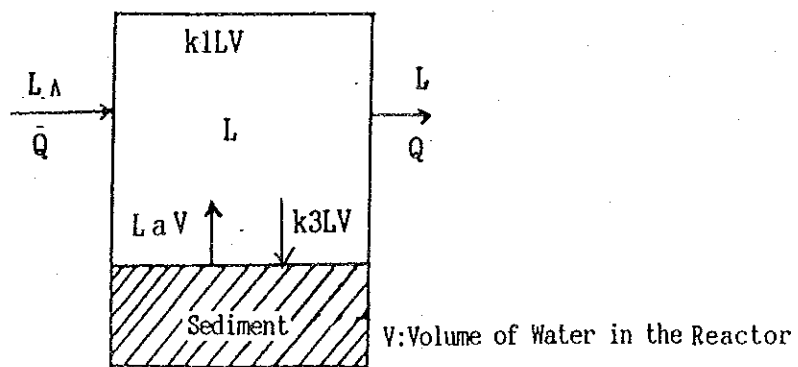Oxygen Consumption Test

Fig. 4.2-1(2) Mass Balance of Water Quality

As indicated in Fig. 4.2-1 (2), L represents the volume of water property present in the reaction bottle which is determined by multiplying L_A (water quality in the reaction bottle) by Q (flow amount). The balanced equation for L is equation (1).

$$V \frac{dL}{dt} = L_A Q - LQ + LaV - k_1 LV - k_3 LV \tag{1}$$

where,

L = Concentration of organic and nutrient in the reactor

L_A = Concentration of organic and nutrient in influent water

La = Release rate

k_1 = Deoxidation Constant

k_3 = Settling Constant

V = Volume of water in the reactor

Q = Flow rate

Changing equation (1) would result in the equation (2).

$$\frac{dL}{dt} = \frac{L_A}{t} + La - L(1/T + k_1 + k_3) \tag{2}$$

where,

T = V/Q : Hydraulic retention time

If the equation (2) uses L = Lo when boundary conditions t = 0, the calculation would be conducted as shown in the third equation (3).

$$L = \frac{L_A/T + La}{1/T + k_1 + k_3} - (\frac{L_A/T + La}{1/T + k_1 + k_3} - Lo) \exp(-t/T - k_1 t - k_3 t) \tag{3}$$

If COD, N and P are the items consumed from the release of BOD, k_1 is disregarded in the third equation. k_3 (items settling in the sediment) will also be disregarded due to the use of filtered inflow of sea water. Changes in the equation (3) would lead to the equation (4).

$$L = \frac{L_A/T + La}{1/T} - (\frac{L_A/T + La}{1/T} - Lo) \exp(-t/T) \tag{4}$$

If the equation (4) is used to solve the release rate La, the

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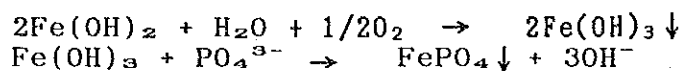equation (5) will be used.

$$L_o = L_n, \quad L = L_{n+1}$$

$$La = H \left[1/T \left\{ L_{n+1} - L_n \exp(-t/T) \right\} / \left\{ 1 - \exp(-t/T) \right\} - L_A \right] \quad (5)$$

where,

La	=	Release rate	$(g/m^2/day)$
H	=	Water depth in the reactor	(m)
T	=	Hydraulic retention time of water in the reactor	(day)
L_n	=	Measured water quality of effluent at the sampling time of n	(mg/l)
L_{n+1}	=	Measured water quality of effluent at the following sampling time of n	(mg/l)
t	=	Interval between n and n+1	(day)
L_A	=	Measured water quality of reservoir	(mg/l)

The experiments were carried out under aerobic and anaerobic conditions due to variations in the release mechanism of phosphorus by the DO concentrations in the pore water at the surface layer of sediment. This condition is basically explained through the chemical formula below.

1). Oxidation Process (aerobic condition)

$$2Fe(OH)_2 + H_2O + 1/2O_2 \rightarrow 2Fe(OH)_3 \downarrow$$
$$Fe(OH)_3 + PO_4^{3-} \rightarrow FePO_4 \downarrow + 3OH^-$$

2). Deoxidation Process (anaerobic condition)

$$Fe(OH)_3 \rightarrow Fe(OH)_2 \rightarrow Fe^{2+} + 2PO_4^{3-}$$
$$FePO_4 \rightarrow Fe_3(PO_4)_2 \rightleftarrows 3Fe^{2+} + 2PO_4^{3-}$$
$$SO_4^{2-} \rightarrow S^{2-}$$
$$Fe_3(PO_4)_2 + 3S^{2-} \rightarrow 3FeS \downarrow + 2PO_4^{3-}$$
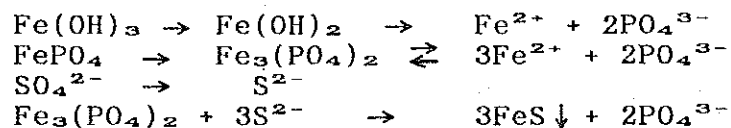
Conclusively, PO_4^{3-} becomes $FePO_4$ under aerobic conditions and will not be released to settle together with $Fe(OH)_3$ in the surface layer of sediment. On the other hand, $Fe_2 +$ becomes FeS under anaerobic conditions and settles, consequently releasing PO_4^{3-}.

4.2.2   Outline of the Experiment

(1)   Measurement in Phase 2

The samples were collected from the 3 stations showed in Fig. 4.2-2. The experimental apparatus used is specified in Fig. 4.2-1(1).

Fig. 4.2-2 Sampling Stations for Release, Oxygen
Consumption and Settling Tests

Table 4.2-1   Release Rate from Sediment

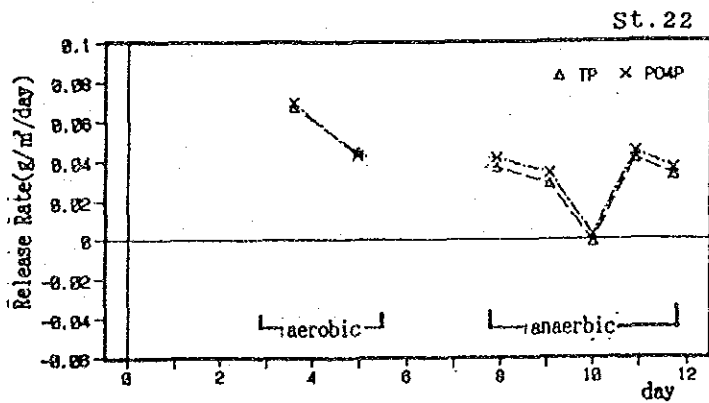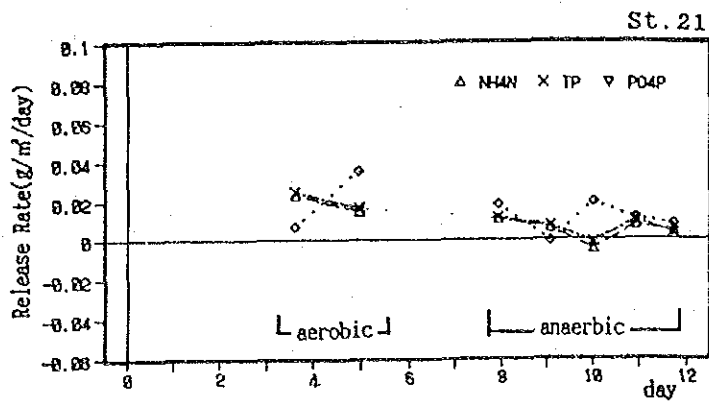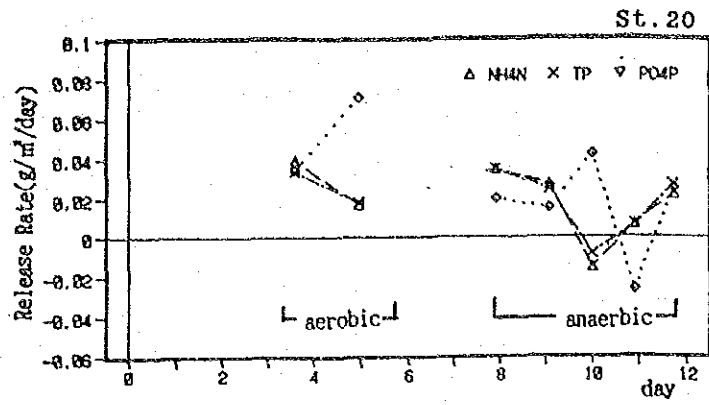| Condition	Item	Release Rate (g/m2/day)					
		Phase2			Phase3		
		St.20	St.21	St.22	St.35	St.36	St.37
Aerobic	COD(Mn)	--	--	--	--	0.111	0.223
	NH4N	0.053	0.021	0.331	0.014	0.032	0.015
	TP	0.028	0.019	0.056	--	--	--
	PO4P	0.025	0.021	0.056	0.019	0.017	0.013
Anarobic	NH4N	0.015	0.011	0.158	0.008	0.010	0.005
	TP	0.015	0.005	0.028	--	--	--
	PO4P	0.017	0.006	0.032	0.021	0.023	0.009
Mean	NH4N	0.034	0.016	0.245	0.011	0.021	0.010
	TP	0.022	0.012	0.042	--	--	--
	PO4P	0.021	0.014	0.044	0.020	0.020	0.011

Fig. 4.2-3 Change in Release Rate-Phase 2

The experiment was carried out for 13 days. Experiments under aerobic conditions were carried out in the first 6 days, while the remaining 7 days were used to experiment under anaerobic conditions. The supplying water was aerated in the reservoir to make the DO saturated condition. Under anaerobic conditions, Na_2SO_3 was added in the reservoir for DO=0.

NH_4-P, TP and PO_4-P were analyzed in the inflowing and outflowing water using the, "Standard Method for the Examination of Water and Wastewater" in USA.

(2)   Survey Measurement in Phase 3

The experimental period carried out in Phase 2 was short and no discrepancy was observed from the release rates measured during the consecutive experimentations under aerobic and anaerobic conditions. In contrast, the experimental period in the third phase was long and experiments under aerobic and anaerobic conditions were carried out separately.

The samples were collected from the stations specified in Fig. 4.2-2. The apparatus used in Phase 2 was also used.

The experiments in Phase 3 were carried out for 32 days. COD(Mn), NH_4-N and PO_4-P were the items analyzed in the outflowing and inflowing water.

(3)   Results

The results obtained from the Phase 2 survey measurements are shown in Fig. 4.2-3, Table 4.2-1 and Table APP 4.2-1(1)-(6) while those obtained from Phase 3 are shown in Fig. 4.2-4(1),(2), Table 4.2-1 and Table APP 4.2-1(7)-(12), and the concentration of organic matters and nutrients in the sediments, were used at the experiments, are shown in Table APP 4.2-2(1)-(7).

The release rate of COD(Mn) range from 0.111 - 0.223 (g/m²/day) showing a mean value of 0.167(g/m²/day). The release amount in the entire Bay area was observed to be 58.8 ton/day.

The release rate of BOD was not measured. But the concentrations of BOD showed high correlations with COD(Mn) in the upper layer and the concentration ratio of both properties was used to estimate the BOD release rate (0.262 g/m²/day). The release amount in the entire Bay area was observed to be 92.2 ton/day.

Experimental results under aerobic conditions exceed the NH_4-N release rate measured under anaerobic conditions, although it is reported that the release rate of NH_4-N is hardly effected by the DO concentration in the layer above the sediment. However this result seems to be obtained due to the reasons mentioned below: the experiments were carried out first under aerobic followed by
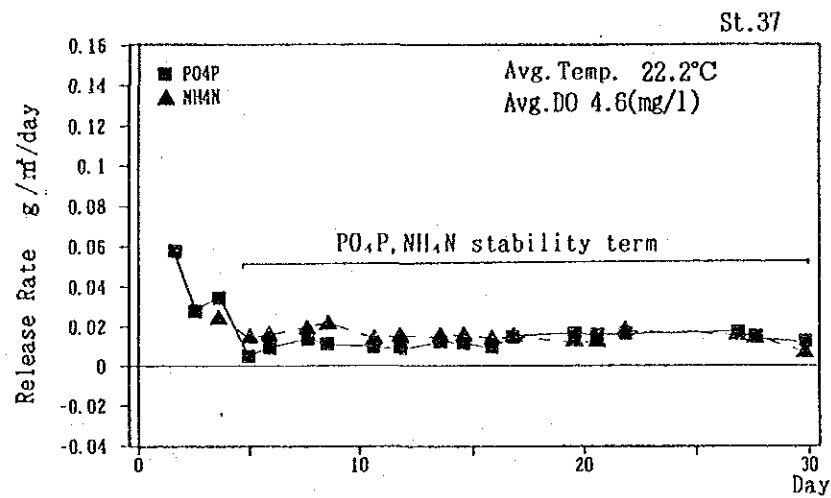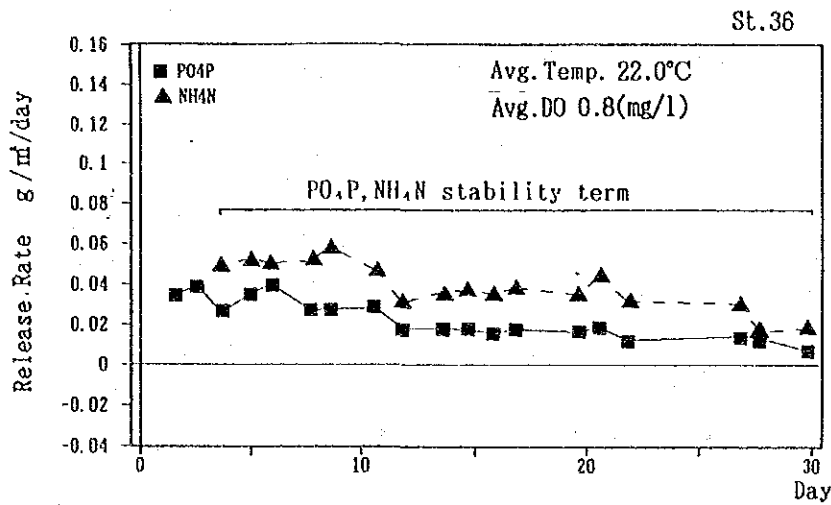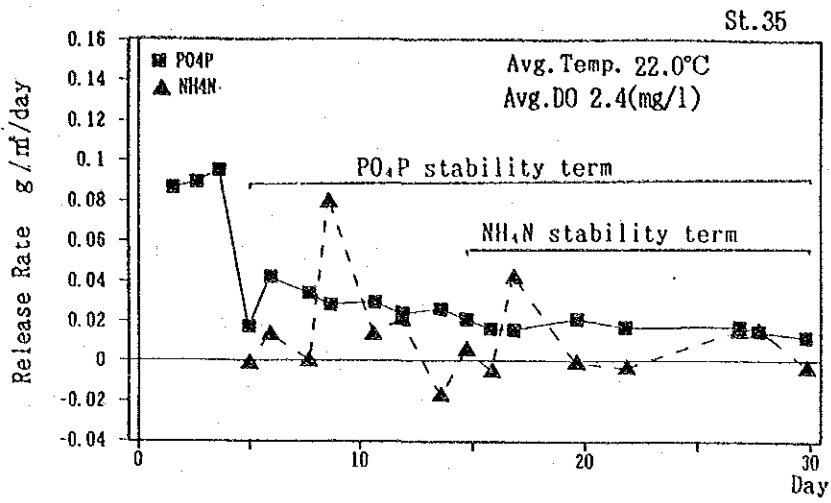
4-16

Fig. 4.2-4(1) Change in Release Rate-Phase 3 (aerobic condition)
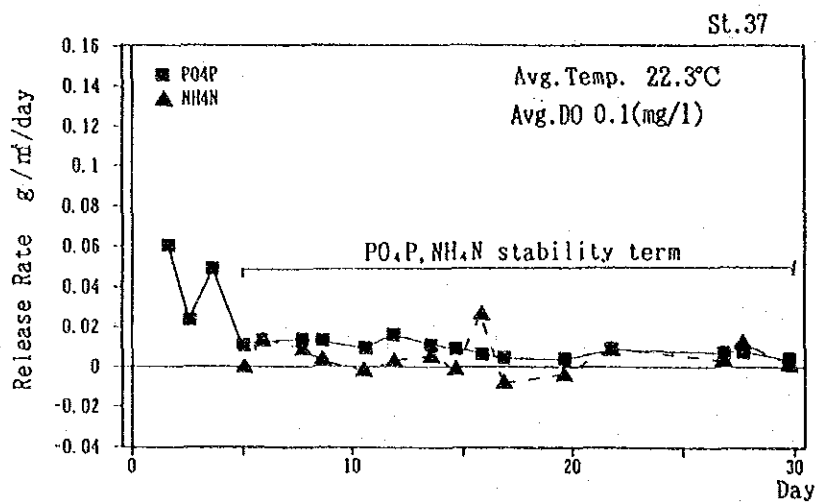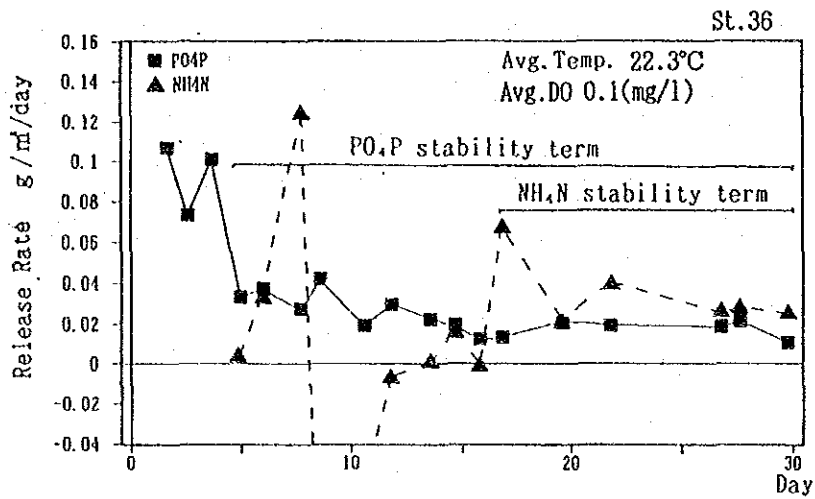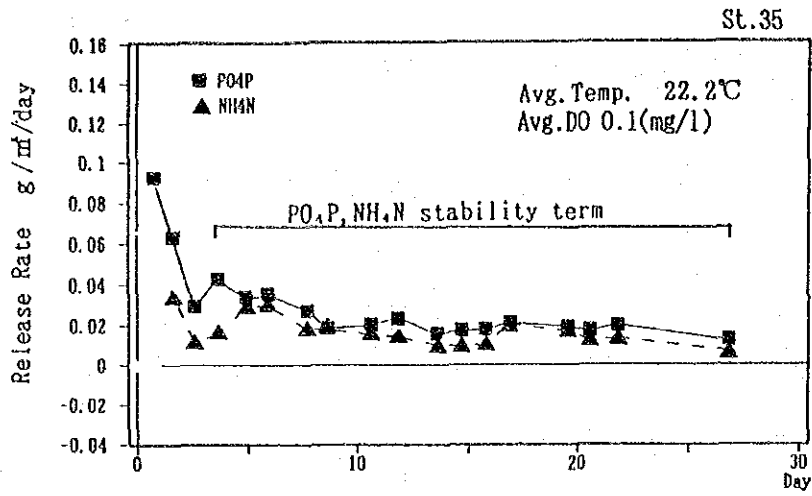
Fig. 4.2-4(2) Change in Release Rate-Phase 3 (anaerobic condition)

anaerobic conditions in the same reactors. The causes of the pressurized extraction of pore water and the discharge of large amounts of NH_4-N thought to have occurred in the initial stage (aerobic condition) remain unidentified.

Phosphorus has no relation whatsoever with the DO concentration conditions. TP and PO_4-P concentrations are observed to be almost the same; phosphorus is usually released in the form of PO_4^{3-}.

As previously mentioned, the release rate of phosphorus should be large under anaerobic conditions and small under aerobic conditions. However almost equal rate or the reverse of the aforementioned observation.

Although studies were not carried out for the investigation and verification of these factors, the following were derived from existing data:

1). Among the sediments used in the experiments under reduced conditions, Fe^{2+}, the element which controls the release of PO_4- P, combines with S^{2-} and is insufficient. Hence, even if oxygen is supplied fully during the experiment, the absence of Fe^{2+}, would release PO_4^{3-}.

2). It is established that Fe SiO_3, prior to its change to Fe^{3+}, combines with PO_4^{3-} under aerobic condition and settles. Hence, PO_4^{3-} is released even if oxygen is sufficient.

3). When Fe^{3+} form a complex ion and is maintained in a dissolved state, it does not combine with PO_4^{3-}. Hence, PO_4^{3-} is released even under aerobic condition.

Given the above reasons and based on the experiments carried out, the release rates of Nitrogen and Phosphorus are thought to be of no relation to the DO concentrations in the upper layer. The mean of the results taken under aerobic and anaerobic conditions was used to represent the release rates at each sampled station.

Using this mean value, the release rates of phosphorus and nitrogen were concluded to be in larger values in the western inner Bay than in other areas. Although it was low coefficient between release rate and the concentrations of nitrogen and phosphorus in the sediments were used at the experiments, according to the results of the surface sediment survey, the stations where low release rate of PO^4-P and NH_4-N showed high coefficients almost coincide with the areas of colloid and clay, and the stations where low release rate of these showed almost coincide with the areas of silt and sand.

Consequently, the mean release rate of the colloid and clay areas are estimated by release rate values of St.20, 22, 35, and 36. These of silt and sand areas are estimated by values of St.21 and 37 (Table APP 4.2-3).

The mean release rate and amount of NH_4-N and PO_4-P in the entire Bay area were estimated by using all values measured in the Experiment 1).

Probably due to the location of St.22, where is near the river mouth with large loads, this Station has exceptionally high release rates of NH_4-N and PO_4-P. And, the area, where these high release rates were adopted to, is considered to be small, thus the release rates at this Station were excluded 2).

    1). When all values measured were used
        NH_4-N
            Release Rate   : 0.033 g/m^2/day
            Release Amount : 11.6 ton/day

        PO_4-P
            Release Rate   : 0.018 g/m^2/day
            Release Amount : 6.3 ton/day

    2). When the value measured in St.22 was excluded
        NH_4-N
            Release Rate   : 0.014 g/m^2/day
            Release Amount : 4.9 ton/day

        PO_4-P
            Release Rate   : 0.016 g/m^2/day
            Release Amount : 5.6 ton/day

4.3   Settling Rate of Particles

Laboratory experiments were carried out on samples taken from the upper layers of 6 stations (Fig. 4.2-2) to grasp the settling rate of the nutrients and organic particles in Guanabara Bay.

4.3.1 Experimental Apparatus and Theory

A vinyl tube with an inner diameter of 0.1m and a length of 1.1m was the apparatus used in the experiment.

Settling rate of particles is calculated as the distance of particles moving downwards per unit time. The product of particle concentration by settling rate is represented as the amount of mass transmitting per unit time and per unit area.

Settling rate was estimated by the following equation;

$$V = F/C$$

where,

V	=	Settling rate	(m/day)
F	=	Flux	(mg/m²/day)
C	=	Concentration particles in the water	(mg/l)

However, this equation uses the flux measured at the site to determine the settling rate, a method that differs from the calculation of settling rate by using settling tubes. But since changes in the concentration of particles were very small in the upper layers of the tubes during the experimental period, the site method was used instead with definitions below: the mean concentrations of particles obtained during the period in the upper layers of the tubes was applied as C, and the total settled amount during the experimental period on the bottom of the tubes was as F in the site method equation.

4.3.2   Outline and Results of the Experiment

An indicated in Fig. 4.2-2, the samples were extracted from the upper layers at 6 stations. The experiment was carried out in a dark room for 3 days, sampling was carried out 7 times in the upper and lower layers halfway through the experiment period. Three days after, sediments were sampled together with a little volume of water.

The COD(Mn), TOC, KN and TP contents in the samples were analyzed using the Standard Method for the Examination of Water and Waste WAter of USA. The results of the analysis on water qualities are shown in Table APP 4.3-1(1)-(6).

The results of the measurements are sited in Table 4.3-1.

The settling rate of all TP, TN and COD(Mn) were observed to be high in the southern part of the Bay (Stns. 41 and 42) and in Botafogo.

A smaller settling rate was obtained in the water from the inner part of the Bay.

Particles in the inner Bay area are supposed to be mainly composed of phytoplankton, because higher Chl-a concentrations are always found in this area.

Plankton, especially chain forming diatoms, are commonly highly buoyant and it partly results in the smaller settling rate in the inner Bay area.

By using the settling rate, the estimation at each station was measured based on the mean annual concentrations of COD(Mn), KN, and TP (Table 4.3-2).

4.4   Oxygen Consumption by Sediment

Table 4.3-1 Results of Settling Tests

St.	Settling Velocity (m/day)			
	T-P	K-N	COD (Mn)	TOC
38	0.156	0.087	0.041	0.056
39	0.084	0.039	0.047	0.033
40	0.060	0.038	0.081	0.042
41	0.145	0.108	0.084	0.128
42	0.203	0.207	0.065	0.143
43	0.152	0.152	0.084	0.096

Table 4.3-2 Total Settled Amount

St.	Settling Amount (g/m2/day)		
	TP	KN	COD(Mn)
38	0.023	0.013	0.206
39	0.017	0.056	0.231
40	0.016	0.067	0.268
41	0.017	0.093	0.221
42	0.023	0.178	0.171
43	0.015	0.142	0.198

The samples extracted from 3 stations during the Phase 2 and 3 survey measurements were examined in the laboratory to determine the amount of oxygen absorbed by the sediments in Guanabara Bay.

4.4.1 Experimental Apparatus and Theory

The experimental apparatus used in the release test was employed. The theories and results derived from the analysis are as follows:

The C(DO) balance equation is represented by equation (1) (Fig.4.4-1).

$$V \frac{dC}{dt} = C_A Q - CQ - D_B V - k_1 L V \qquad (1)$$

Where,

C	=	Concentration of DO in the reactor
Ca	=	Concentration of DO in influent water
O_B	=	O_2 consumption rate
k_1	=	Deoxidation Constant
l_3	=	Settling Constant
V	=	Volume of water in the reactor
Q	=	Flow rate

Changes in the above equation would lead to the equation (2).

$$\frac{dC}{dt} = \frac{C_A}{T} - \frac{C}{T} - D_B - k_1 L \qquad (2)$$

Where,

T   =   V/Q : Hydraulic retention time

If the equation (2) results in t = 0 and C = Co, calculations would be according to the equation (3).

$$C = T(C_A/T - D_B - k_1 L) \{1 - \exp(-t/T)\} + Co \exp(-t/T) \qquad (3)$$

If the O_2 consumption items represented by D_B are to be calculated, the equation (4) below will be used.

$$C_o = C_n, \qquad C = C_{n+1}$$
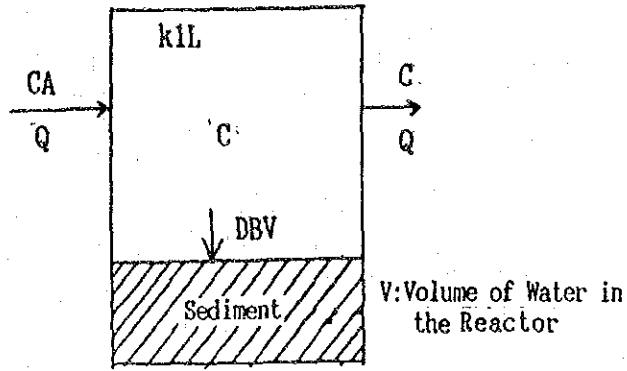
Fig. 4.4-1 Mass Balance of DO
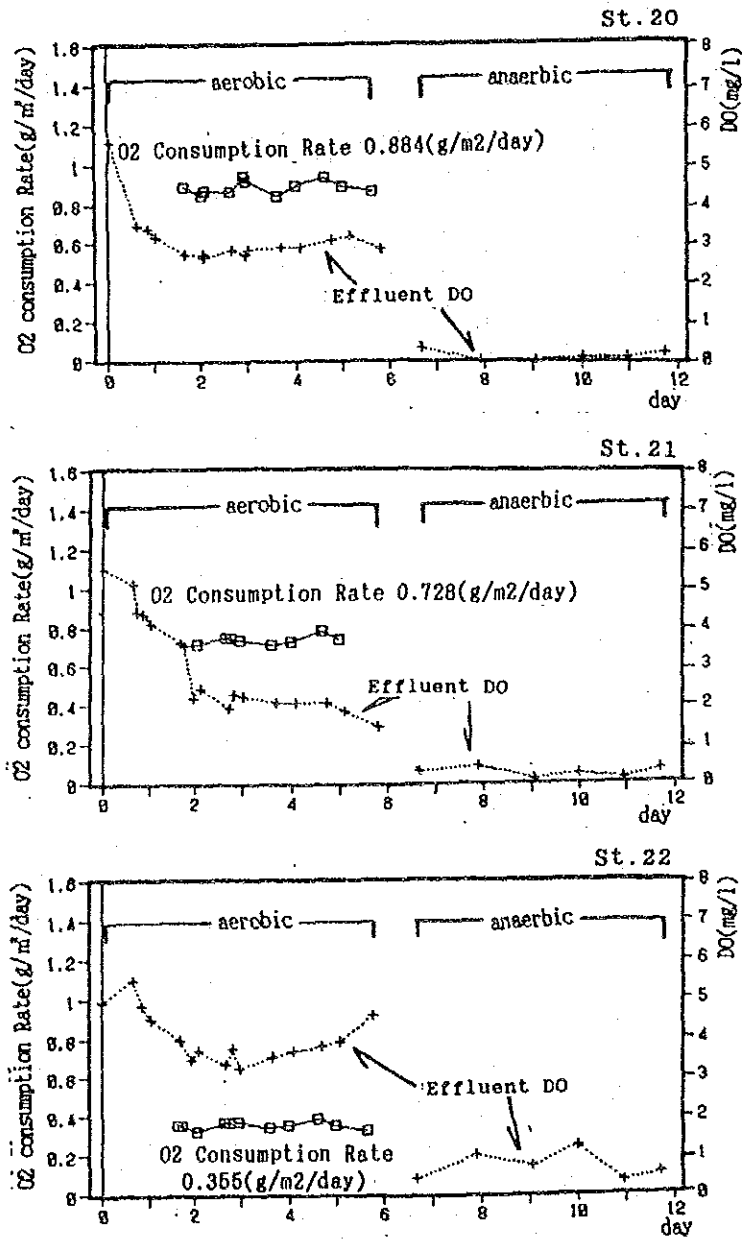
Fig. 4.4-2 Change in Oxygen consumption Rate-Phase 2

$$D_B = H [-1/T [C_{n+1}/ \{ 1 - \exp(-t/T) + C_n \exp(-t/T) \}] - C_A/T - k_1 L] \qquad (4)$$

where,

D_B	=	O_2 consumption rate by sediment	(g/m²/day)
H	=	Water depth in the reactor	(m)
T	=	Retention time on the reactor	(day)
C_n	=	Measured DO concentration of effluent water at the sampling time of n	(mg/1)
C_{n+1}	=	Measured DO concentration of effluent water at the following sampling time of n	(mg/1)
t	=	Interval between n and n+1	(day)
C_A	=	Measured DO concentration of reservoir water	(day)
K_1	=	Constant of O_2 consumption rate by water in the reactor	(day⁻¹)
L	=	Ultimate BOD $(=BOD_5/(1-e^{-k_1*5}))$	(mg/1)

L and k_1 were determined from the BOD concentrations of outflow, using the slope method by Thomas H.A. (Table APP 4.4-1(1), (2)).

4.4.2   Outline and Results of the Experiment

The stations for sampling and the apparatus used in the experiment were similar to those used in the release test.

The Phase 2 survey measurements were carried out for 6 days from the 31st of October to the 6th of November 1992.   The Phase 3 measurements were carried out for 32 days from the 8th of April to the 7th of May 1993.

To create aerobic conditions in the reaction bottles, aeration was carried out in the reservoir.

DO concentrations in the inflow and outflow, including water temperature, were measured.   A DO meter was used to measure DO concentration.

The results of experimental measurements and calculations are shown in the Appendix Table APP 4.4-2(1)-(6).

The Phase 2 results on the measurement of oxygen consumption indicate that approximately 0.9 g/m²/day is St.20, 0.7 g/m²/day in St.21,   and 0.35 g/m²/day in St.22 (Fig. 4.4-2).   The Phase 3 results indicate that 0.7 g O_2/day was consumed at Station 35, 0.8 g O_2/day at Station 36, and 0.65 g O_2 at Station 37 (Fig. 4.4-3).

The mean O_2 consumption rate and O_2 consumption amount in the entire Bay area were calculated using all values measured in the

St.35

St.36

St.37
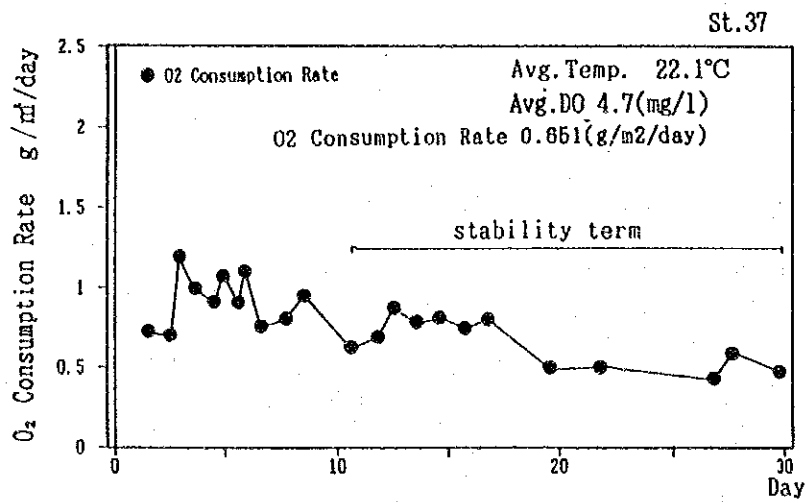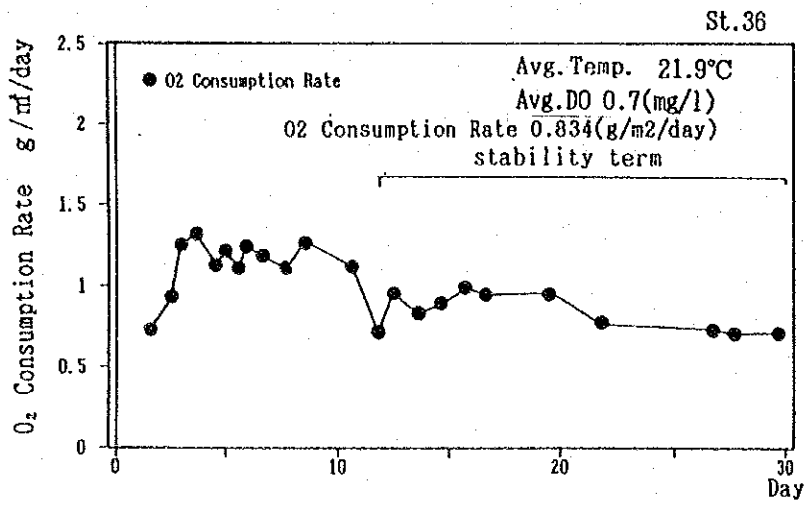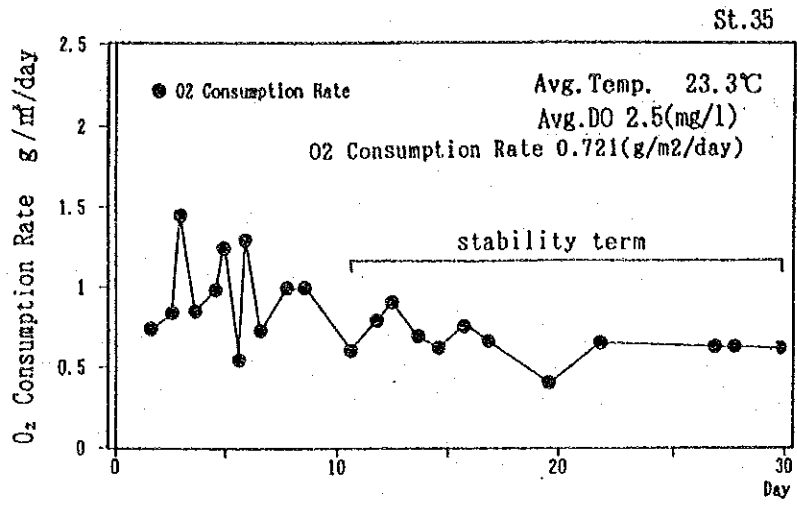
Fig. 4.4-3 Change in Oxygen consumption rate-Phase 3

experiment 1) and by excluding the value measured at St.22 from all values measured 2), by the same reason as employed for the release rate.

   1). When all values measured were used
         O_2 Consumption Rate   : 0.74 g/m^2/day
         O_2 Consumption Amount : 260 ton/day

   2). When the value measured in Station 22 was excluded
         O_2 Consumption Rate   : 0.72 g/m^2/day
         O_2 Consumption Amount : 253 ton/day

If the underwater concentration of DO in the Guanabara Bay is about 7 mg/l, and if there is no DO supply, O_2 consumption above mentioned will become a DO=0 potential for about 60 days.

As indicated in the water quality survey results, the composition of organic materials underwater and O_2 consumption by sediments are thought to largely affect constant low DO concentrations in the lower layers of Guanabara Bay.

CHAPTER 5

NUTRIENT SUPPLY AND ITS CYCLE
IN THE BAY

CHAPTER 5

NUTRIENT SUPPLY AND ITS CYCLE IN THE BAY

Guanabara Bay is for the grater part a shallow closed estuary, which is strongly affected by inflowing of fresh water and human activity, in the surrounding densely populated areas, through the many rivers that flow into the Bay.

Hence, the water condition has complex and regional characteristics the different nutrient environments were found. Consequently, different internal production mechanisms.

There may be areas in the Bay where specific characteristics of the water quality and nutrient environment can be obtained. These characteristics were summarized and the phosphorus cycle, for the dry and wet seasons.

5.1   Methods for Determination

5.5.1   Sub-area

Depending mainly on the pollution degree, which was decided by the concentrations of nutrient and organic materials in the surface layer, the Bay area was divided to five sub-areas plus the two small bays (Fig. 5.5-1).

5.1.2   Season

The dry season, April - September, 1992, and the wet season, October, 1992 - March, 1993, are considered, although April seems to be the transiting stage from the wet to the dry season and occasionally has quite high precipitation.

Several measurements and experiments, however, were performed in March and April, 1993. There was a lot of rain in April of 1993, therefore, it was difficult to say that this month belongs to the dry season.

Several differences water quality and the nutrient environment were found in May and June, therefore, some points were referred to these two months.

5.1.3   Layer

All sub-areas are thought to be composed of two layers the euphotic layer (upper) and the decomposing layer (lower).

The depths of the euphotic layer were determined using the Secchi-disk depth at each station; in the dry season they were

Fig. 5.1-1   Sub-areas divided based on the
              Degree of Pollution

multiplied by a factor of 2.1, which was obtained in preliminary survey-1, April, 1992. While, in the wet season a factor 2.9 was used, which was obtained in the primary productivity measurement-1, November, 1992.

Both factors were empirically obtained from the Bay, therefore, it was more suitable determination in the Bay than using the factor 2.6, which is often employed.

The lower depth was determined by subtracted the euphotic depths from the mean water depths in each area based on MSL (Mean Sea Level).

5.1.4 Mean Concentration and Standing Stock of Nutrient in each Sub-area

Based on the measured concentrations of water quality properties the mean concentrations in the euphotic (upper) and the decomposing (lower) layers at each station were calculated from the analytical values obtained in each layer by the weighted average method taking the depth of the samples into consideration (Table 5.1-1 and 2).

The standing stock in each layer at each station was calculated by the mean concentration multiplying the water volume of each layer within the sub-area.

TN and TON at several stations were not measured. However, these values were calculated using their correlation with TP (TN = 5.2 TP + 0.39), and TON=TN-DIN.

5.2 Characteristics of Water Quality in each Sub-area

Measured concentrations of water quality properties in each sub-area is summarized in Table 5.2-1.

5.2.1 Jurujuda Bay

This is small bay located on the southeastern side area near the mouth of Guanabara Bay.

A supplementary survey was once carried out in this area on April 1, 1993 for the simultaneous surveys.

As shown in Chapter II, water in the inner part of Jurujuda is more highly polluted than the inner part of Guanabara Bay; TN, Chl-a, COD(Mn) were higher than in the inner Guanabara Bay in the wet season.

Table 5.1-1(1)   Water Volume, Depths of Euphotic and Decomposing Layers, and Mean
Concentrations at each Station (Dry Season)

St.	Layer	Depth (m)	COD(Mn) (g/m3)	TN (g/m3)	TON (g/m3)	DIN (g/m3)	TP (g/m3)	POP (g/m3)	PO4-P (g/m3)	Water volume (x 10⁻6 m3)
3	Upper	4.5	1.01	0.785	0.547	0.238	0.086	0.020	0.045	41.53
	Lower	11.2	0.86	0.732	0.486	0.247	0.068	0.009	0.040	126.40
4	Upper	2.8	2.33	1.028	0.763	0.216	0.197	0.050	0.067	16.10
	Lower	3.9	0.98	0.816	0.645	0.171	0.082	0.020	0.034	22.43
5	Upper	4.5	1.79	1.024	0.766	0.258	0.122	0.024	0.046	58.50
	Lower	17.5, 3.3	0.76	0.780	0.566	0.214	0.075	0.011	0.033	184.90
6	Upper	3.5	1.94	0.616	0.628	0.222	0.111	0.020	0.035	84.00
	Lower	8.4, 7.5	0.96	0.421	0.424	0.217	0.072	0.022	0.030	193.95
7	Upper	2.5	2.08	1.440	1.067	0.373	0.202	0.065	0.075	42.88
	Lower	2.0	1.66	0.946	0.597	0.349	0.107	0.028	0.058	34.30
8	Upper	2.5	2.88	2.391	1.927	0.984	0.374	0.080	0.202	11.88
	Lower	0.8	2.36	1.887	1.383	0.782	0.277	0.063	0.164	3.80
9	Upper	2.5	2.05	1.521	0.838	0.688	0.288	0.055	0.168	42.88
	Lower	2.0	1.55	1.054	0.563	0.493	0.163	0.040	0.103	34.30
10	Upper	2.5	2.65	1.300	1.092	0.208	0.175	0.046	0.043	64.75
	Lower	8.3, 2.5	1.58	0.978	0.807	0.171	0.113	0.038	0.034	196.12
11	Upper	2.5	2.78	0.935	0.755	0.194	0.166	0.076	0.024	23.76
	Lower	0.8	2.73	0.985	0.795	0.201	0.139	0.005	0.021	10.80
12	Upper	2.5	1.30	0.801	0.543	0.258	0.079	0.035	0.019	64.75
	Lower	8.3, 0.8	1.13	0.718	0.480	0.238	0.063	0.016	0.021	196.12
13	Upper	1.7	7.55	2.348	1.604	1.273	0.369	0.123	0.194	50.58
	Lower	0.0	7.45	2.313	1.561	1.388	0.356	0.150	0.181	0.70
14	Upper	1.7	5.38	1.244	0.813	0.431	0.197	0.075	0.098	48.54
	Lower	1.1	2.84	0.812	0.507	0.306	0.080	0.035	0.046	36.96
15	Upper	2.5	1.88	0.764	0.625	0.139	0.072	0.039	0.017	80.63
	Lower	0.4	1.56	0.707	0.489	0.218	0.061	0.026	0.025	12.90
16	Upper	2.5	1.82	0.682	0.511	0.171	0.073	0.045	0.020	80.63
	Lower	0.4	1.57	0.614	0.386	0.229	0.063	0.033	0.020	12.90
17	Upper	2.5	3.50	0.579	0.485	0.094	0.072	0.034	0.038	92.25
	Lower	0.9	3.73	0.607	0.425	0.182	0.074	0.034	0.043	100.03
18	Upper	1.7	6.67	0.989	0.792	0.284	0.153	0.059	0.072	51.51
	Lower	3.3	4.82	0.891	0.615	0.304	0.108	0.051	0.054	99.99
J	Upper	3.6	4.00	1.440	1.200	0.240	0.180	-	0.030	25.20
	Lower	0.8	2.200	1.120	0.890	0.230	0.120	-	0.030	5.60

5-4

Table 5.1-1 (2)　　　　　Water Volume, Depths of Euphotic nd Decomposing Layers, and Mean
Concentrations at each Station (Wet Season)

St.	Layer	Depth (m)	COD(Mn) (g/m3)	TN (g/m3)	TON (g/m3)	DIN (g/m3)	TP (g/m3)	POP (g/m3)	PO4-P (g/m3)	Water volume (x 10^6m3)
3	Upper	6.5	1.97	0.186	0.163	0.165	0.074	0.035	0.021	76.56
	Lower	11.5	1.39	0.133	0.105	0.147	0.057	0.015	0.022	135.70
4	Upper	3.5	2.39	0.832	0.629	0.203	0.085	0.050	0.026	19.25
	Lower	2.9	1.89	0.837	0.592	0.245	0.086	0.040	0.035	15.95
5	Upper	3.5	2.51	0.822	0.657	0.165	0.083	0.025	0.016	42.00
	Lower	16.4, 9.1	1.63	0.728	0.585	0.143	0.065	0.030	0.028	180.38
6	Upper	2.2	4.36	0.846	0.734	0.129	0.107	0.065	0.012	96.26
	Lower	8.8	2.57	0.748	0.561	0.158	0.080	0.025	0.030	381.04
7	Upper	2.2	5.12	1.700	1.356	0.344	0.252	0.130	0.058	44.00
	Lower	3.1	3.46	1.076	0.754	0.322	0.132	0.075	0.057	62.00
8	Upper	2.2	4.33	2.245	1.455	0.780	0.318	0.130	0.150	12.65
	Lower	0.2	3.06	1.745	1.117	0.633	0.248	0.105	0.122	1.15
9	Upper	2.2	3.73	1.700	1.263	0.525	0.299	0.160	0.080	43.56
	Lower	1.0	2.93	0.975	0.676	0.470	0.224	0.069	0.080	61.38
10	Upper	2.2	3.81	1.108	1.005	0.103	0.138	0.065	0.022	95.26
	Lower	8.8	1.78	0.900	0.686	0.214	0.098	0.025	0.031	381.04
11	Upper	2.2	6.06	1.360	1.144	0.216	0.158	0.080	0.016	23.76
	Lower	1.0	3.51	1.102	0.842	0.261	0.108	0.050	0.019	10.80
12	Upper	2.2	3.91	1.087	1.022	0.065	0.134	0.060	0.018	74.36
	Lower	7.2	2.10	0.842	0.633	0.209	0.087	0.025	0.034	243.36
13	Upper	0.7	6.30	3.149	1.967	1.183	0.446	0.175	0.189	21.00
	Lower	0.9	4.80	2.644	1.467	1.178	0.383	0.170	0.196	27.00
14	Upper	1.2	5.76	2.064	1.857	0.212	0.245	0.140	0.021	74.40
	Lower	3.1	3.69	1.462	1.229	0.244	0.166	0.060	0.027	192.20
15	Upper	2.0	6.17	1.030	0.917	0.113	0.123	0.095	0.010	62.00
	Lower	2.5	2.23	0.801	0.571	0.230	0.079	0.055	0.018	77.50
16	Upper	2.0	5.96	0.841	0.708	0.134	0.094	0.055	0.010	79.60
	Lower	0.0	4.41	0.909	0.675	0.234	0.084	0.045	0.010	0.00
17	Upper	2.0	4.01	1.020	0.921	0.099	0.169	0.100	0.012	39.60
	Lower	1.7	3.71	0.858	0.701	0.157	0.112	0.075	0.015	33.66
18	Lower	1.2	9.46	2.192	1.940	0.252	0.358	0.220	0.027	74.40
	Lower	3.1	4.26	1.254	1.020	0.235	0.195	0.155	0.025	192.20
19	Upper	0.7	6.87	2.642	1.281	1.361	0.433	0.109	0.200	1.93
	Lower	1.9	4.69	1.971	0.761	1.210	0.304	0.050	0.175	5.23
J	Upper	1.8	4.0	1.440	1.200	0.240	0.180	-	0.030	13.05
	Lower	2.7	2.2	1.120	0.890	0.230	0.120	-	0.030	19.58

Table 5.1-2(1)   Mean Standing Stock in Sub-areas in the Dry Season

Area	Station	COD(Mn) (ton)		TN (ton)		TON (ton)		DIN (ton)		TP (ton)		POP (ton)		PO4-P (ton)	
		Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
J	J	100.8	12.3	36.3	6.3	30.2	5.0	6.0	1.3	4.5	0.7	-	-	0.8	0.2
E	11	66.1	29.5	22.2	10.6	17.9	8.6	4.6	2.2	3.9	1.5	1.8	0.1	0.6	0.2
NE	15	151.6	20.1	61.1	9.1	50.4	6.3	11.2	2.8	5.8	0.8	3.1	0.3	1.4	0.3
	16	146.7	20.3	55.0	7.9	41.2	5.0	13.8	3.0	5.9	0.8	3.6	0.4	1.6	0.3
	17	333.4	373.1	55.1	60.7	46.2	42.5	9.0	18.2	6.9	7.4	3.8	3.4	3.6	4.3
	Sub total	631.7	413.5	171.2	77.7	137.8	53.8	34.0	24.0	18.6	9.0	10.5	4.1	6.6	4.9
NW	13	381.1	5.2	118.8	1.6	81.1	1.1	64.4	1.0	18.7	0.2	6.2	0.1	9.8	0.1
	14	261.1	105.0	60.4	30.0	39.5	18.7	20.9	11.3	9.6	3.0	3.6	1.3	4.8	1.7
	18	343.6	482.0	50.9	89.1	40.8	61.5	14.6	30.4	7.9	10.8	0.9	5.1	3.7	5.4
	Sub total	985.8	592.2	230.1	120.7	161.4	81.3	93.9	42.7	36.2	14.0	10.7	6.5	18.3	7.2
W	7	89.2	56.9	61.8	32.5	45.8	20.5	16.0	12.0	8.7	3.7	2.8	1.0	3.2	2.0
	8	34.2	9.0	28.4	7.2	22.9	5.3	11.7	3.0	4.4	1.1	1.1	0.2	2.4	0.6
	9	87.9	53.2	65.2	36.2	35.9	19.3	29.5	16.9	12.3	5.6	2.4	1.4	7.2	3.5
	Sub total	211.3	119.1	155.4	75.9	104.6	45.1	57.2	31.9	25.4	10.4	6.3	2.6	12.8	6.1
Central	3	41.9	108.7	32.6	92.5	22.7	61.4	9.9	31.2	3.6	8.6	0.8	1.1	1.9	5.1
	5	104.7	140.5	59.9	144.2	44.8	104.7	15.1	39.6	7.1	13.9	1.4	2.0	2.7	6.1
	6	163.0	186.2	51.7	81.7	52.8	82.2	18.6	42.1	9.3	14	1.7	4.3	2.9	5.8
	10	171.6	309.9	84.2	191.7	70.7	158.2	13.5	33.5	11.3	22.2	3.0	7.5	2.8	6.7
	12	84.2	221.6	51.9	140.7	35.1	94.1	16.7	46.7	5.1	12.4	2.3	3.1	1.2	4.1
	Sub total	565.4	966.9	280.3	650.8	226.1	500.6	73.8	193.1	36.4	71.1	9.2	18.0	11.5	27.8
	4	37.5	22.0	16.6	18.3	12.3	14.5	3.5	3.8	3.2	1.8	0.8	0.4	1.1	0.8
Total		2598.6	2155.5	912.1	960.3	690.3	708.9	279.0	299.0	128.2	108.5	39.3	31.7	51.7	47.2

* TN : Calculated from correlation with TP   TN=5.2 x TP + 0.39
* TON = TN - TIN
* Mean values measured in April. '93 in Jurujuba Bay are used for dry and wet seasons.

Table 5.1-2(2)   Mean Standing Stock in Sub-areas in the Wet Season

Area	Station	COD(Mn) (ton)		TN (ton)		TON (ton)		DIN (ton)		TP (ton)		POP (ton)		PO4-P (ton)	
		Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
J	J	52.2	21.9	18.8	21.9	15.7	17.4	3.1	4.5	2.3	2.3	-	-	0.4	0.6
E	11	144.0	37.9	32.3	11.9	27.2	9.1	5.1	2.8	3.8	1.2	1.9	0.5	0.4	0.2
NE	15	382.5	172.9	63.8	62.1	56.8	44.3	7.0	17.8	7.6	6.1	5.3	4.3	0.1	1.4
	16	474.4	0.0	66.9	0.0	56.4	0.0	10.7	0.0	6.7	0.0	4.4	0.0	1.6	0.3
	17	517.8	818.8	163.1	241.0	144.3	196.0	18.7	45.2	26.6	37.5	4.0	2.5	2.0	4.8
	Sub total	1374.7	991.7	293.8	303.1	257.5	240.3	36.4	63.0	40.9	43.6	14.3	6.8	3.7	6.5
NW	13	132.3	129.6	66.1	71.4	41.3	39.6	24.8	31.8	9.4	10.3	3.7	4.6	4.0	5.3
	14	428.5	709.2	153.6	281.0	138.2	236.2	15.3	46.9	18.2	31.9	10.4	11.5	1.6	5.2
	18	703.8	818.8	163.1	241.0	144.3	196.0	18.7	45.2	26.6	37.5	16.4	29.8	2.0	4.8
	Sub total	1264.6	1657.6	382.8	593.4	323.8	471.8	59.3	123.9	54.2	79.7	30.5	45.9	7.6	15.3
W	7	225.3	214.5	74.8	66.7	59.7	46.7	15.1	20.0	11.1	8.2	5.7	4.7	2.6	3.5
	8	54.8	3.5	28.4	2.0	18.4	1.3	9.9	0.7	4.0	0.3	1.6	6.5	1.9	0.1
	9	162.5	179.8	74.1	59.8	55.0	41.5	22.9	28.9	13.0	13.7	7.0	4.2	3.5	4.8
	19	13.2	24.5	4.6	8.7	2.0	2.4	2.6	6.3	0.8	1.6	0.2	0.3	0.4	0.9
	Sub total	455.8	422.3	181.9	137.2	135.1	91.9	50.5	55.9	28.9	23.8	14.5	15.7	8.4	9.3
Centr	3	150.8	188.3	14.2	18.0	12.5	14.2	12.6	19.9	5.7	7.7	2.7	2.0	1.6	3.0
	5	105.4	294.0	34.5	131.3	27.6	105.5	6.9	25.8	3.5	11.7	1.1	5.4	0.7	5.1
	6	415.3	979.3	80.6	285.0	69.9	213.8	12.3	60.2	10.2	30.5	6.2	9.5	1.1	11.4
	10	362.9	678.3	105.5	342.8	95.7	261.3	9.8	81.5	13.1	37.3	9.5	16.4	2.1	11.8
	12	290.7	511.1	80.8	205.0	76.0	154.1	4.8	50.9	10.0	21.2	4.5	6.1	1.3	8.3
	Sub total	1325.1	2651.0	315.6	982.1	281.7	748.9	46.4	238.3	42.5	108.4	24.0	39.4	6.8	39.6
	4	46.0	30.1	16.0	13.4	12.1	9.5	3.9	3.9	1.6	1.4	1.0	0.6	0.5	0.6
Total		4662.4	5812.5	1241.2	2063.0	1053.1	1588.9	204.7	492.3	174.2	260.4	86.2	108.9	27.8	72.1

* Calculated using TN=5.2 TP + 0.30: obtained by this survey

Table 5.2-1 Measured Concentrations of Water Qulity Parameters in the Surface Layer in each Sub-area

Area / Parameter	Season	Jurujuba	East	Northeast	Northwest	West	Central	Botafogo
Salinity	Dry	28.1-29.5	26.5-30.7	27.5-31.9	26.3-31.5	27.3-31.8	28.3-33.8	32.7-34.1
(%)	Wet	--	14.5-19.3	8.7-17.2	19.7-23.0	23.1-29.2	21.2-32.3	29.7-31.3
Temperature	Dry	27.5-28.4	25.0-26.2	24.6-27.7	25.3-27.9	25.1-27.1	24.2-27.8	24.3-25.6
(°C)	Wet	--	25.5-28.1	25.1-27.7	25.5-27.5	24.2-25.8	22.3-26.1	23.8-24.3
DO (surface)	Dry	95 - 211	85 - 138	104 - 204	56 - 306	27 - 91	31 - 186	96 - 249
(%)	Wet	--	--	126 - 208	9 - 216	76 - 129	86 - 135	100 - 128
DO (bottom)	Dry	5 - 61	74 - 121	22 - 65	4 - 72	7 - 52	13 - 107	71 - 90
(%)	Wet	--	--	27 - 32	10 - 32	12 - 51	43 - 108	61 - 88
Transparency	Dry	0.3 - 1.0	0.9 - 1.1	0.7 - 1.8	0.4 - 1.5	0.8 - 1.4	0.8 - 3.5	0.4 - 2.0
(m)	Wet	--	0.5 - 0.8	0.4 - 0.8	0.2 - 0.4	0.6 - 1.0	0.7 - 3.0	0.8 - 1.5
TN	Dry	0.63-3.04	0.80-1.31	0.52-1.31	0.83-3.01	0.84-4.11	0.37-1.58	--
(mg/l)	Wet	--	1.31-1.85	0.71-1.41	1.41-4.12	1.90-2.89	0.64-1.49	--
NO3-N	Dry	0.01-0.07	0.20-0.30	0.00-0.35	0.02-0.15	0.04-0.30	0.01-0.30	0.08-0.25
(mg/l)	Wet	--	0.03-0.10	0.01-0.10	0.02-0.07	0.03-0.05	0.01-0.07	0.06-0.06
NH4-N	Dry	0.01-0.06	0.04-0.09	0.01-0.10	0.02-1.75	0.15-1.15	0.00-0.20	0.04-0.10
(mg/l)	Wet	--	0.08-0.10	0.00-0.10	0.09-1.50	0.02-1.00	0.00-0.15	0.08-0.10
TP	Dry	0.10-0.60	0.10-0.20	0.07-0.10	0.10-0.55	0.08-0.60	0.05-0.25	0.06-0.50
(mg/l)	Wet	--	0.15-0.25	0.10-0.20	0.20-0.70	0.20-0.45	0.07-0.20	0.08-0.15
PO4-P	Dry	0.01-0.10	0.02-0.04	0.00-0.06	0.00-0.30	0.01-0.30	0.00-0.09	0.00-0.15
(mg/l)	Wet	0.01-0.02	0.01-0.02	0.01-0.01	0.01-0.30	0.01-0.20	0.01-0.03	0.01-0.02
Chl-a	Dry	21 - 132	13 - 138	11 - 82	39 - 225	11 - 72	3 - 62	5 - 139
(ug/l)	Wet	--	74 - 201	17 - 68	25 - 111	8 - 116	4 - 167	8 - 24
COD (Mn)	Dry	4.2 - 11.0	1.8 - 2.8	1.8 - 4.2	3.0 - 9.4	1.6 - 4.4	0.6 - 4.2	1.0 - 5.8
(mg/l)	Wet	--	7.2 - 8.8	2.0 - 8.6	3.6 - 11.0	4.0 - 6.2	2.4 - 6.6	3.0 - 4.2

5.2.2   Eastern Sub-area

St. 11 in the simultaneous surveys and St. 39 in supplementary survey are included in this area, although the supplementary survey was carried out in a different season from the simultaneous surveys, It, therefore, is hard to compare them.

River discharge strongly affects the surface salinity values in this area not only in the wet season but also in the dry season.

DO(%) at the bottom was higher than in other areas and the values were almost the same as those found at the surface, because of the shallow depth despite this area being quite highly polluted.

Considerably high chl-a occurred at times in the wet season.

5.2.3   Northeastern Sub-area

Stns. 15, 16 and 17 are included in this area.

Reflecting the strong river discharge in the wet season, salinity values were very low.

Surface DO was always and at all stations higher than 100 %, but, Chl-a was not very high.

Concentration of nitrogen and phosphorus were lower than in other areas, especially NH_4-N, NO_3-N and PO_4-P were occasionally not detected. In particularly, PO_4-P was zero in many surveys.

5.2.4   Northwestern Sub-area

Stns. 13, 14 and 18 were included, although water quality at St. 13 sometimes had different characteristics from the other two stations.

This sub-area appears to be highly affected by large river discharges with high pollution loads of salinity, nitrogen and phosphorus, particularly NH_4-N and PO_4-P in the surface layer, which function as nutrients for plankton production. Consequently, high Chl-a results in low transparency, and high surface DO values.

5.2.5   Western Sub-area

Stns. 7, 8, 9 and 19 are included in this area.
The second highest nutrient concentrations in the Bay were obtained here.

However, these high concentration of nutrients do not seem to be transferred into internal production, which was indicated by low

concentrations of Chl-a and organic materials.

5.2.6   Central Sub-area

This sub-area, including Stns. 3, 5, 6, 10 and 12, is the least polluted in the Bay, because of the location of the stations, most of which are located on the trench which is the deepest part of the Bay. Through this trench clean offshore water penetrates into the inner part of this area and demonstrates the effect of offshore water.

Besides, there are only two small rivers flowing into this sub-area and hence the load from outside form the Bay was also quite small. Nutrient move into this area, mainly from other sub-areas, Eastern, Northeastern and Western areas.

5.2.7   Botafogo Bay

This is small bay located on the southwestern side near the mouth of the Bay. St. 4 is located in this area.

The water quality reflects both the off-shore water and the adjacent populated area.

High salinity, low temperature, lowest of the minimum Chl-a values and high bottom DO values which is results from not only the low oxygen consumption by the sediment but also offshore water coming into through the lower layer.

While the maximum values of nitrogen and phosphorus observed in this area were higher than those in the central area. They appears to be the result of human activity.

5.3   Effectiveness of Phosphorus and Nitrogen in Phytoplankton Production

5.3.1   Relationships between Chl-a and TP, and TN

A quantitative balance between the nutrient uptaken by phytoplankton and those recovered after decomposition is often found in the upper strata in the open sea and in lakes. In this state of equilibrium there is considered to be a good relationship between Chl-a and TP or TN.

However, because of the very complicated environmental condition and complicated production mechanism of this condition, it is not found in estuaries.

Fig. 5.3-1 shows the relationship between TP and Chl-a in the euphotic layer of the Bay, in which almost all the points lie under the line for water having the equilibrium condition in
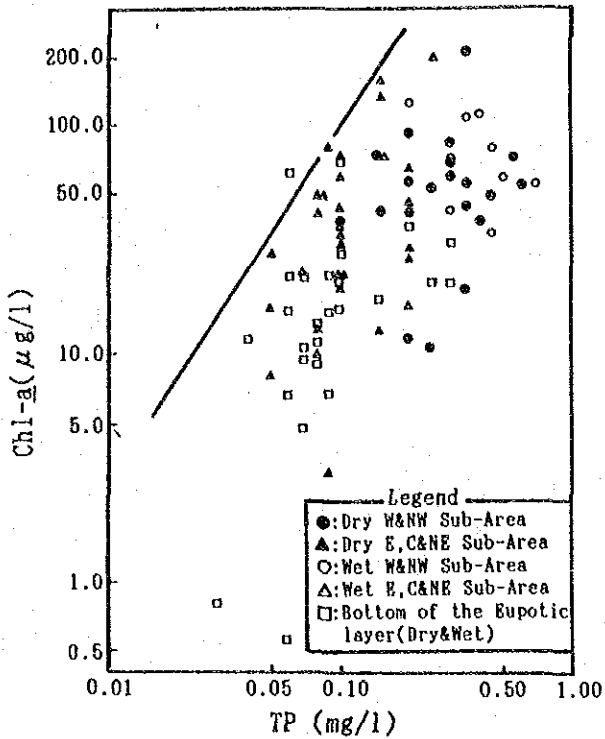
Fig. 5.3-1 Relationship between Chl-a and TP in the Euphotic Layer

line: Relationship between Chl-a and TP for water being in the equilibrium condition
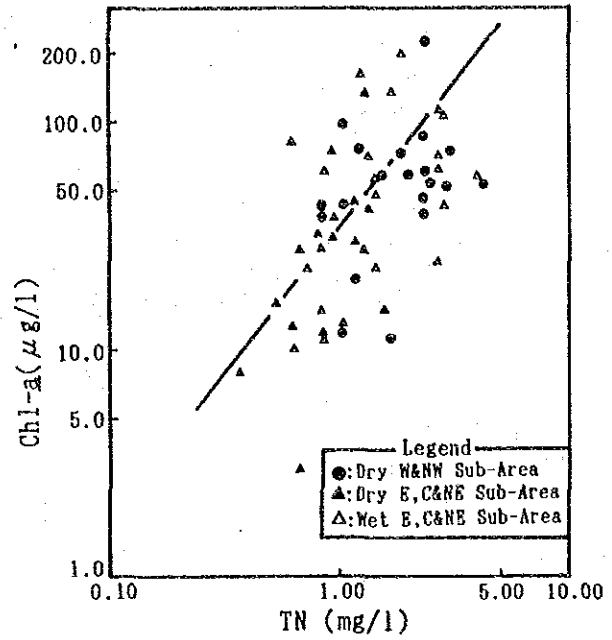

Fig. 5.3-2 Relationship between Chl-a and TN in the Euphotic Layer

line: Relationship between Chl-a and TN for water being in the equilibrium condition

Table 5.3-1 Effectiveness of Nutrients in Phytoplankton Production (%)

Sub-area	May *POP	May 'PON	June *POP	June 'PON	November *POP	November 'PON
E	71±1	38±22	81±1	43±17	80±2	65±5
NE	89±11	72±15	54±1	30±22	88±3	69±13
C	74±18	49±29	41±1	25±26	68±1	32±32
NW	86±16	52±33	23±8	16±19	71±2	66±21
W	56±17	21±18	29±1	28±18	65±8	51±18
B	90±10	-	41±1	-	60±2	-

*: POP/(POP + DIP) (%)
': PON/(PON + DIN) (%)

Table 5.3-2 Correlation between Phosphorus and Nitrogen in the Different Sub-areas

Month	E, NE and C sub-area	NW and W sub-area
May	TN = 2.86 TP + 0.79 (r=0.24)	TN = 5.23 TP + 0.45 (r=0.90)
	PON = -0.42 POP + 0.59 (r=0.03)	PON = 4.38 POP + 0.004 (r=0.74)
	DIN = 2.47 DIP + 0.20 (r=0.31)	DIN = 5.26 DIP + 0.36 (r=0.88)
Jun.	TN = 2.84 TP + 0.47 (r=0.77)	TN = 6.82 TP - 0.25 (r=0.92)
	PON = 0.71 POP + 0.14 (r=0.34)	PON = 5.26 POP - 0.24 (r=0.91)
	DIN = -0.26 DIP + 0.18 (r=0.05)	DIN = 5.75 DIP - 0.26 (r=0.84)
Nov.	TN = 4.48 TP + 0.49 (r=0.65)	TN = 3.78 TP + 1.15 (r=0.85)
	PON = 0.64 POP + 0.39 (r=0.08)	PON = 4.13 POP + 0.28 (r=0.66)
	DIN = -0.48 DIP + 0.13 (r=0.09)	DIN = 3.62 DIP + 0.26 (r=0.80)

lakes.

It indicates that an equilibrium condition regarding phosphorus
is not found in the Guanabara Bay and that a phosphorus deficient

condition for phytoplankton production had existed.

While, the same relationship of Chl-a with TN suggests an equi-
librium condition regarding nitrogen exists in the Bay, although
TN was measured in the euphotic surface layer at the nearly half
of the regular stations (Fig. 5.3-2).

5.3.2   Effectiveness of Phosphorus and Nitrogen
         in Phytoplankton Production

(1) Planktonic-P and planktonic-N

If a high correlation between Chl-a and POP (or PON) occurred,
the POP (PON) on the Y-axis indicates the amount of non-living
POP (PON), when the Chl-a value is equal to zero. The amount
of living or planktonic-P (planktonic-N) is calculated by sub-
tracting the non-living POP (PON) from POP (PON).

However, correlation Chl-a to POP (PON) was not generally found,
except in May for POP.

Although it was not measured the actual amount of plantonic-P
(planktonic-N) in POP (PON) is thought to be large, from the
fact that high Chl-a was always observed in the greater part of
the Bay.

It also was suggested that a large amount of DIP(DIN) quickly
transferred into planktonic-P (-N), from the fact that despite
the high Chl-a concentration, low, sometimes very low, DIP values
were observed at many stations and on many occasions.

Therefore, the ratio of the mean POP (PON) to the sum of the mean
POP (PON) and the mean DIP (DIN) in the euphotic layer in each
sub-area indicates how effectively DIP (DIN) produce
plnaktonic-P (-N), when the values are at similar levels (Fig.
5.3-3 and Table 5.3-1).

DIP was more effectively transferred to planktonic-P in May
than in June and slightly more than in November.

In June, in almost all sub-areas, DIP was used at its lowest
efficiency, especially in the Northwestern and Western sub-areas,
where more DIP was found and lower Chl-a values were obtained
than in the other two months.

While, DIN was less effectively transferred to PON in all months
than DIP to POP. DIN was also transferred to PON and its lowest
level in June. The reasons mentioned below may be the cause of
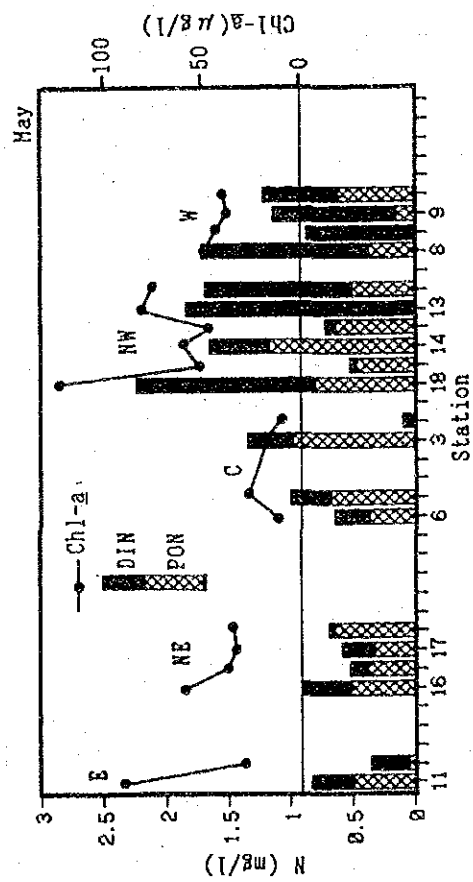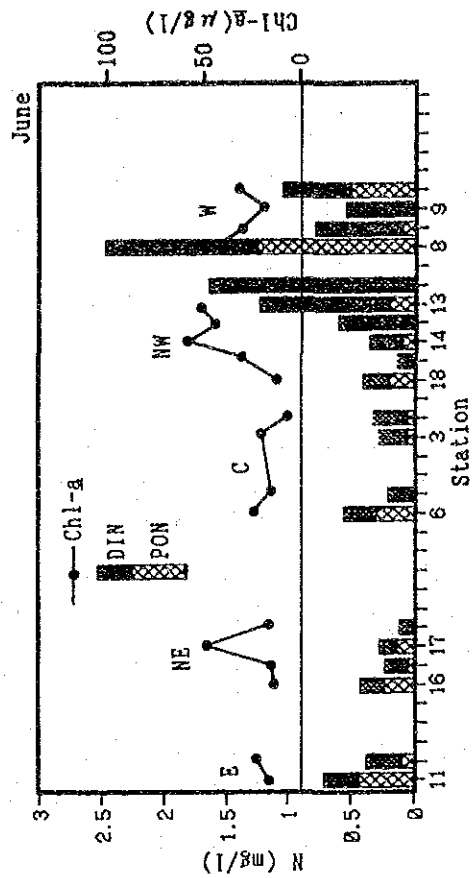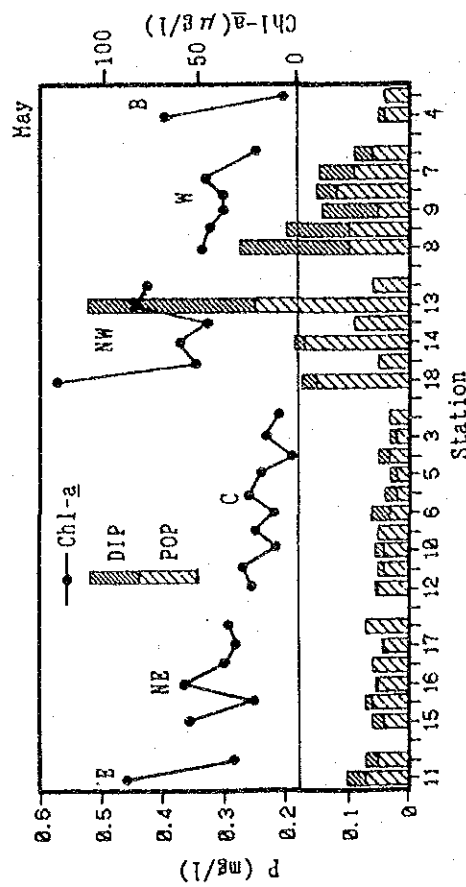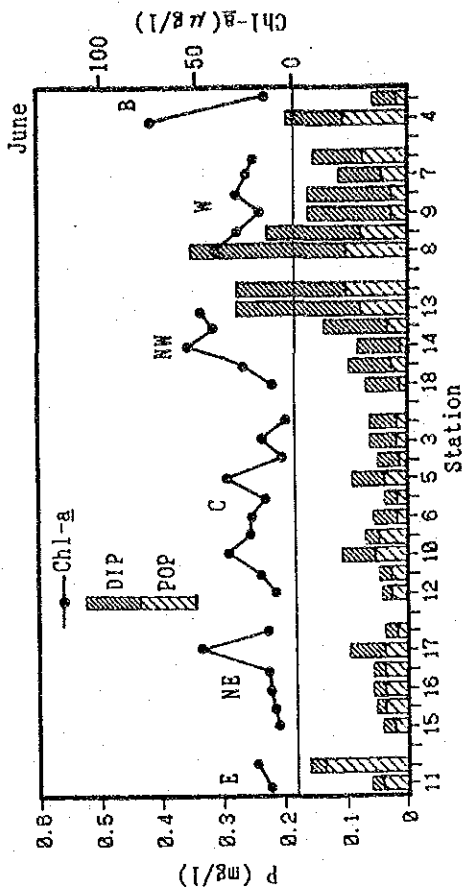its low effectiveness in June; the dominant phytoplnakton group

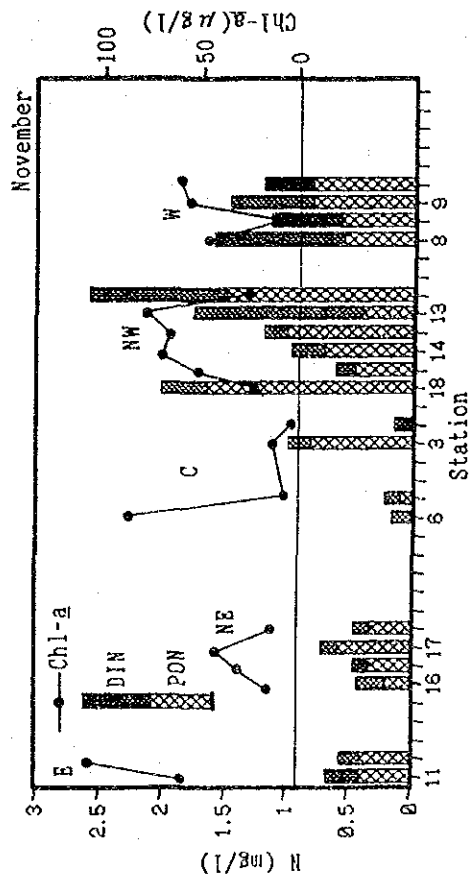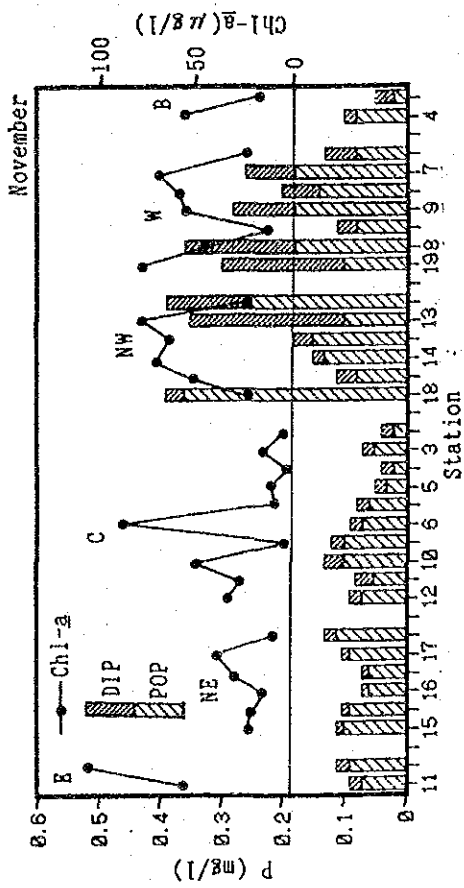Fig. 5.3-3   Effectiveness of Nutrients in Phytoplankton Production

Fig. 5.3-3 (Continued)

(Bacillariophyceae) was different from in May (Nostocophyceae),
salinity was slightly higher and the temperature was slightly
lower than in May.

November, is in the wet season and the greater discharge from the
rivers causes the greater amount of fresh water inflows to the
Bay. Besides, of course, rainfall occurred more often than in
June, and widely speaking fresh water is often the cause the
location of red tide (extraordinary plankton production).

Therefore, the environmental condition in June seems to be less
suitable for production than in May and November.

(2) Relationship between phosphorus and nitrogen in plankton
     and the environment

It is said that the offshore phytoplankton usually uptakes DIN
and DIP with a ratio obtained by the stoichiometiric formula
(N/P: 7.2 by weight), hence the ratio of DIN to DIP in the sur-
rounding water controls phytoplankton production, consequently
the deficient DIN or DIP becomes the limiting factor for produc-
tion.

However, in a neritic sea area or estuary the ratio varies great-
ly according to the water quality conditions, seasons and phyto-
plankton physiological conditions.

In Guanabara Bay, for the relationships between TN and TP, PON
and POP, and DIN and DIP; the regional differences were greater
than the monthly differences (Fig. 5.3-4).

In May, June and also November, high concentrations of all forms
of phosphorus and nitrogen were found in the Northwestern and
Western sub-areas, also in these areas a high correlations be-
tween all forms of nitrogen and phosphorus were observed (Table
5.3-2).

The ratios of nitrogen to phosphorus in plankton (indicated by
PON to POP, as mentioned in the previous section) by weight were
4.4 (May), 3.8 (June) and 5.6 (November). When the environmental
nutrients are sufficient for phytoplanpkton production, the
uptake ratio of N to P is similar to those obtained for the
cultured species : 2.6 - 7.9 for Chrysophyceae, 2.7 - 6.8 for
Bacillariophyceae and 5.6 - 6.0 for Diniphyceae (Parsons et al,
1961).

This indicates that under sufficient concentrations of nutrients,
phytoplankton is not controlled by the N/P ratio in the environ-
ment. Production occurring like that in Guanabara Bay is likely
to be controlled more greatly by other factors, such as the light
intensity, salinity value and mainly plankton physiological
condition at the surface. Further, when a lot of phytoplankton is
produced at the surface the production in the deeper layers
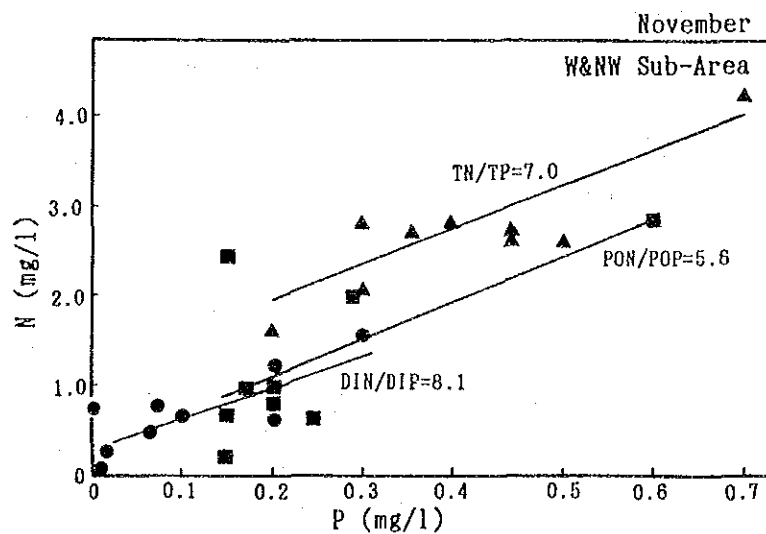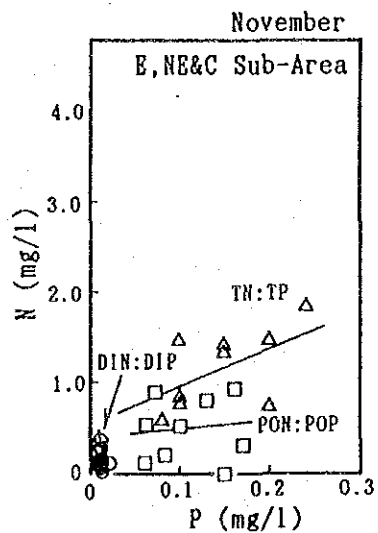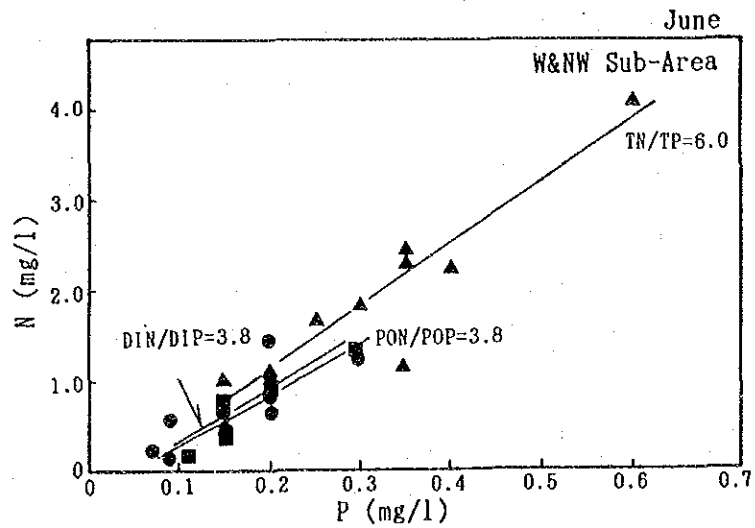inhibited. As mentioned in 4.1, light inhibition occurred at many
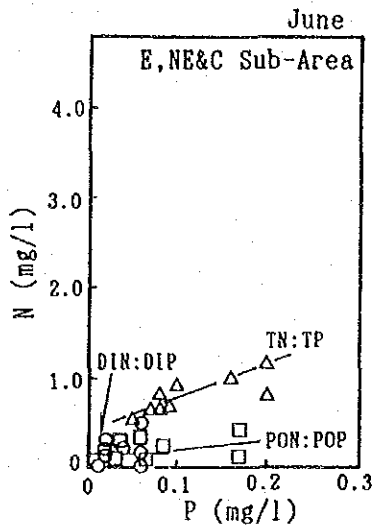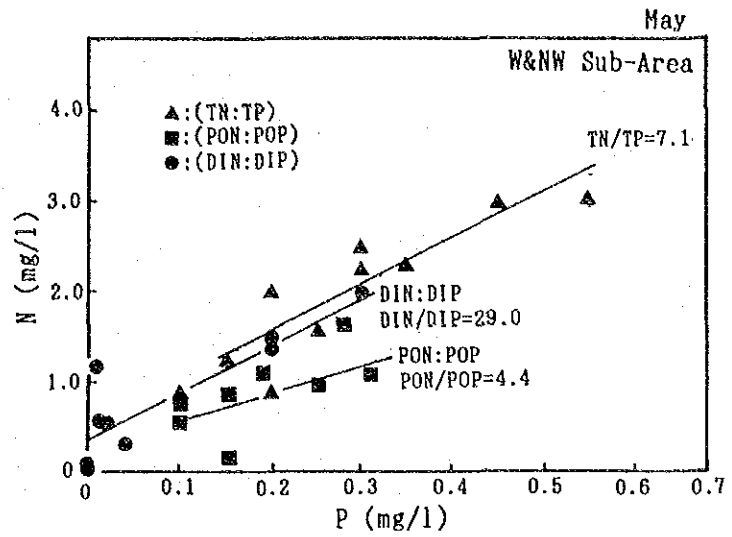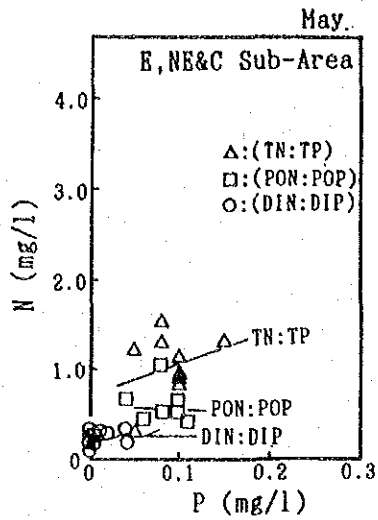
Fig. 5.3-4   Relationship between Phosphorus and Nitrogen in
              Plankton and the Environment

stations.

On the other hand, in the Eastern, Northeastern and Central sub areas, the concentrations of all forms of nitrogen and phosphorus were much lower and the correlations between all forms were lower than in the other two area, in the three months (Table 5.3-2).

DIP was not detected at many stations which indicates that phytoplankton uptook nearly all the DIP in the water. However, a lot of Chl-$\underline{a}$ was observed on all occasions meaning that production occurs even when DIP is nearly zero, although it is usually thought that the lowest possible concentration of DIP required for uptake is around 3 to 16 ug/l.

Even under these conditions for DIP, it appears that production occurs in these areas provided that the existence of high available concentrations of DIN in the surrounding water are controlled by N and P concentrations rather than the ratio.

Therefore, it seems reducing the inflow of DIN is a significant measure in lowering phytoplankton production in the Eastern, Northeastern and Central sub-areas.

5.4   Water Mass Balance in the Bay

5.4.1   Discharge from Rivers

Most of water flowing into the Bay is from rivers.

The total flowing water volume is the sum of discharges from the rivers, direct inflowing from industries, wastewater treatment plant (WWST), storm drainage (RSS) and waste disposal site (SWDS) and also rainwater. The mean discharge in the dry season is 5.38 x 10^6 m^3/day and the wet season is 24.39 x 10^6 m^3/day.

5.4.2   Precipitation

Total precipitation around the Bay from April to October, 1992, was 350 mm. Mean daily precipitation over the entire Bay in the dry season was 0.71 x 10^6 m3.

While total precipitation from October to March was 1330 mm, so the mean daily precipitation in the wet season is 2.62 x 10^6 m^3/Bay.

5.4.3   Water Volume Exchange through the Bay Mouth

Water flows into the Bay was 94.18 x 10^6 m^3 in the dry and 91.58 x 10^6 m^3 in the wet seasons.

While, the volume flowing out was 109.73 x 10^6 m^3/day in the dry

Table 5.4-1   Water Mass Balance in the Bay

	Dry Season	Wet Season
Precipitation (x 10^6 m3/day)	0.71	2.62
Discharge from Rivers (x 10^6 m3/day)	15.38	24.39
Inflowing through the Bay Mouth (x 10^6 m3/day)	94.18	91.58
Total Inflowing Water Volume (x 10^6 m3/day)	110.27	118.59
Outflowing through the Bay Mouth (x 10^6 m3/day)	109.73	115.78
Evaporation (x 10^6 m3/day)	1.47	1.02
Total Outflowing Water Volume (x 10^6 m3/day)	111.10	116.80

Table 5.5-2   Additional Load caused by Rainwater in the Wet Season (Dec., 1992 and Jan., 1993)

	BOD	COD(Cr)	TP	TKN	COD(Mn)	SS
Mean concentration (mg/l)	<2.0	<10	0.025	0.33	0.7	8
Total load caused by rainwater (ton/day)	0.0	0.0	0.065	0.86	1.82	20.8

Table 5.5-3   Additional Load caused by Rainwater in the Dry Season (May - Sept., 1993)

	BOD	COD(Cr)	TP	TKN	COD(Mn)	SS
Mean concentration (mg/l)	-	32	1.001	2.90	2.2	20
Total load caused by rainwater (ton/day)	-	23.1	0.711	2.10	1.59	14.5

and 115.78 x 10^6 m³/day in the wet season.

5.4.4   Evaporation

Evaporation was not measured this time. A general value, hence, of evaporation is used here, which is 1240 mm/year in the Atlantic Ocean at 20° S (in "The Ocean").

This value was divided to dry and the wet season based on the number of sunny days and with precipitation lower than 1.0 mm : 723 mm (1.47 x 10^6 m3/day/Bay) in the dry season and 517 mm (1.02 x 10^6 m3/day/Bay) in the wet season.

Water Mass Balance in the Bay is calculated per day (Table 5.4-1).

5.5   Flowing Load into the Bay

5.5.1   Flowing Load through Rivers

Table 5.5-1 contents the mean flowing load through rivers into each sub-area in the two seasons, based on the regular surveys of rivers.   These divided areas are based on the sub-areas in the Bay where rivers flow into.

This load being brought at freshet time and seasonal difference of the wet season were taken into account in these figures.

5.5.2   Direct Flowing Load

Direct flowing load from industry, WWST, RSS and SWDS is not a great part of the total flowing load the entire of the Bay.

However, it occupies a great part of the flowing load into the Jurujuba and the Central sub-area, particularly in the Central sub-area the direct flowing loads of all measured items were larger than the loads from the rivers.

5.5.3   Load caused by Rainwater

It is well known that rainwater contains some organic and inorganic material.   These concentrations occasionally are high, especially in the first rainfall after long period of fine weather.

Rainwater in Rio de Janeiro was analyzed several times (Tables 5.5-2 and 3). The first four times high concentrations were not found in the rain water, however, in the dry season level of pollutants in the rainwater were quite high.

The total load entering directly into the Bay area was calculat-

Table 5.5-1　　Direct and Indirect Flowing Load into the Bay

Dry Season

	Discharge (x10⁶m3/d)	BOD (t/d)	COD(Mn) (t/d)	TN (t/d)	TON (t/d)	DIN (t/d)	TP (t/d)	TOP (t/d)	PO4-P (t/d)
Through rivers	0.14	3.50	2.88	1.18	0.83	0.35	0.32	0.22	0.10
Direct inflow		*(6.65)	(0.32)	(0.71)	(0.50)	(0.21)	(0.097)	(0.067)	(0.030)
Rain water	0.014	-	0.03	0.04	-	0.01	0.01	-	-
Jurujuba sub-total	0.15	10.15	3.13	1.93	1.33	0.56	0.43	0.29	0.13
Through rivers	0.15	3.59	2.47	1.02	0.71	0.31	0.28	0.19	0.09
Direct inflow		*(7.23)	(1.22)	(3.04)	(2.13)	(0.91)	(0.352)	(0.243)	(0.109)
Rain water	0.021	-	0.05	0.06	-		0.02	-	-
Central sub-total	0.17	10.82	3.74	4.12	2.84	1.22	0.65	0.43	0.20
Through rivers	0.47	11.66	9.44	3.88	2.72	1.16	1.04	0.72	0.32
Direct inflow		*(6.65)	(0.32)	(0.71)	(0.50)	(0.21)	(0.097)	(0.067)	(0.030)
Rain water	0.208	-	0.45	0.59	-	-	0.20	-	-
Eastern sub total	0.68	18.31	10.21	5.18	3.22	1.37	1.34	0.79	0.35
Through rivers	5.20	35.48	37.30	12.56	8.79	3.77	2.78	1.92	0.94
Direct inflow		*(0.29)	(0.11)	(0.10)	(0.07)	(0.03)	(0.002)	(0.0016)	(0.0006)
Rain water	0.176	-	0.38	0.50	-	-	0.17	-	-
Northeastern sub total	5.38	35.77	41.52	13.16	8.86	3.80	2.95	1.92	0.94
Through rivers	7.19	154.44	124.38	50.33	35.23	15.10	13.34	9.31	4.14
Direct inflow		*(15.11)	(1.61)	(5.77)	(4.04)	(1.73)	(0.097)	(0.067)	0.030
Rain water	0.101	-	0.22	0.29	-	-	0.10	-	-
Northwestern sub total	7.29	169.55	126.21	56.39	39.27	16.83	13.54	9.38	4.17
Through rivers	1.78	50.51	40.79	16.93	11.85	5.08	4.63	3.20	1.44
Direct inflow		*(15.91)	(2.17)	(8.42)	(5.89)	(2.53)	(0.598)	(0.413)	(0.185)
Rain water	0.225	-	0.48	0.64	-	-	0.21	-	-
Western sub-total	2.01	66.42	43.44	25.99	17.74	7.61	5.44	3.61	1.63
Through rivers	0.46	13.27	10.85	4.52	3.16	1.36	1.24	0.86	0.38
Direct inflow		*(5.21)	(0.27)	(0.20)	(0.14)	(0.06)	(0.004)	(0.0028)	(0.0012)
Rain water	0.012	-	0.03	0.03	-	-	0.01	-	-
B. Botafogo sub-total	0.47	18.48	11.15	4.75	3.30	1.42	1.25	0.86	0.38
Through rivers	15.38	272.38	228.62	90.72	63.50	27.22	23.67	16.35	7.34
Direct inflow		*(58.74)	(46.69)	(18.95)	(13.27)	(5.68)	(1.25)	(0.86)	(0.39)
Rain water	0.72	-	1.6	2.1	-	-	0.7	-	-
Total	16.10	331.12	276.91	111.76	76.77	32.85	25.62	17.28	7.80

Wet Season

	Discahrge (x10⁶m3/d)	BOD (t/d)	COD(Mn) (t/d)	TN (t/d)	TON (t/d)	DIN (t/d)	TP (t/d)	TOP (t/d)	PO4-P (t/d)
Through rivers	0.22	4.86	3.86	1.55	0.66	0.99	0.22	0.08	0.07
Direct inflow		*(6.65)	(0.32)	(0.71)	(0.28)	(0.43)	(0.097)	(0.067)	(0.030)
Rain water	0.053	-	0.09	0.04	-	-	0.003	-	-
Jurujuba sub-total	0.27	11.51	4.27	2.40	0.94	1.42	0.32	0.15	0.10
Through rivers	0.19	4.16	3.30	1.42	0.57	0.85	0.19	0.13	0.06
Direct inflow		*(7.23)	(1.22)	(3.04)	(1.22)	(1.82)	(0.352)	(0.243)	(0.109)
Rain water	0.079	-	0.14	0.07	-	-	0.005	-	-
Central sub-total	0.27	11.39	4.66	4.53	1.79	2.67	0.55	0.37	0.17
Through rivers	0.72	16.39	12.84	5.42	2.17	3.25	0.73	0.50	0.23
Direct inflow		*(6.65)	(0.32)	(0.71)	(0.28)	(0.43)	(0.097)	(0.067)	(0.030)
Rain water	0.661	-	1.06	0.50	-	-	0.038	-	-
Eastern sub total	1.38	23.04	14.22	6.63	2.45	3.68	0.87	0.57	0.26
Through rivers	8.60	53.12	66.06	29.87	11.95	17.92	2.31	1.59	0.71
Direct inflow		*(0.29)	(0.11)	(0.10)	(0.04)	(0.06)	(0.002)	(0.0014)	(0.0006)
Rain water	0.672	-	1.23	0.58	-	-	0.044	-	-
Northeastern sub total	9.27	53.41	67.40	30.55	11.99	17.98	2.35	1.59	0.71
Through rivers	11.25	220.45	177.21	74.40	29.76	44.64	9.51	6.56	2.95
Direct inflow		*(15.11)	(1.61)	(5.77)	(2.31)	(3.46)	(0.097)	(0.067)	(0.030)
Rain water	0.353	-	0.64	0.30	-	-	0.023	-	-
Northwestern sub total	11.60	235.56	179.46	80.47	32.07	48.10	9.63	6.63	2.98
Through rivers	2.69	70.55	53.93	22.65	9.06	13.59	3.20	2.21	0.96
Direct inflow		*(15.91)	(2.17)	(8.42)	(3.35)	(5.07)	(0.598)	(0.372)	(0.216)
Rain water	0.737	-	1.33	0.63	-	-	0.047	-	-
Western sub-total	3.43	86.46	57.43	31.70	12.41	18.66	3.85	2.57	1.18
Through rivers	0.63	18.42	14.12	5.97	2.39	3.58	0.85	0.59	0.26
Direct inflow		*(5.21)	(0.27)	(0.20)	(0.08)	(0.12)	(0.004)	(0.003)	(0.001)
Rain water	0.026	-	0.05	0.02	-	-	0.002	-	-
B. Botafogo sub-total	0.72	23.63	14.44	6.19	2.47	3.70	0.86	0.59	0.25
Through rivers	24.39	388.81	332.05	141.64	56.66	84.98	17.06	11.76	5.24
Direct inflow		*(58.74)	(46.69)	(18.95)	(7.56)	(11.39)	(1.25)	(0.83)	(0.42)
Rain water	2.60	-	4.7	2.2	-	-	0.2	-	-
Total	26.99	447.55	383.44	162.79	64.22	96.37	18.43	11.95	5.66

DIN-2 : Mean percentage obtained from several results of rivers (dry - 30 % : wet - 60%)
TON-2 : same as TIN (dry - 70 % : wet - 40 %)
* : Direct inflow COD(Mn)/

	COD(Mn)/BOD	TN/BOD	TP/BOD	
a) WWTP:	0.46	0.43	0.08	a)...Mean values obtained in US
b) RSS:	0.11	0.40	0.04	b)...Mean values obtained in Jurujuba
b) Industry:	0.012	0.08	0.009	

c) SWDS: Ratios used for SWDS same as for RSS
d) Rain water: Mean values of rain water analysis (TIN instead of TN)

ed. It was negligible in the wet season, but in the dry season
it should be added to the total load.

## 5.6   Phosphorus Cycle in the Bay, especially DIP

5.6.1   Factors of Cycle

Figs. 5.6-1 and 2 show the phosphorus cycle in the entire Bay in
the dry and the wet seasons using results of analysis.

The numerical cycle in each sub-area is contained in Tables 5.6-1
and 2.

(1)   Phosphorus uptake

PO_4-P uptake during photosynthesis is theoretically calculated
according to the following stoichiometric formula, then trans-
ferred to planktonic-P (POP):

$$106CO_2 + 16NHO_3 + H_3PO_4 + 122H_2O = (CO_2)_{106}(NH_3)_{16}H_3PO_4 + 138 O_2$$
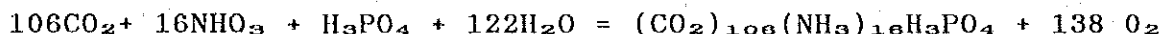
$$DO/O\text{-}P = 138 \times O/P = (138 \times 16 \times 2)/31 = 143$$

The quantity of P uptaken was calculated using the above rela-
tionship for DO/O - P, based on the productivity and respiration
rate per unit area obtained in each sub-area in the wet and the
dry seasons (see Chapter IV, 4.1).

(2)   Respiration rate

The respiration per unit area in the dry season was 37 % of the
net productivity, while in the wet season it was from 40 to 65 %
(see Chapter IV, 4.1).

Although these values are higher than 10 %, which is the common
value for active photosynthesis (Marine Biochemistry, 1973, Tokai
Univ. Publishing), these values were used in the determination of
the phosphorus cycle.

The respiration at night was calculated using recognized value of
30 % of the net productivity (ibid.).

Through respiration, PO_4-P is returned to the environment.

(3)   Release rate of nutrients from the bottom sediment

The release rate calculated were almost same for both seasons and
in all sub-areas (Table APP 5.6-1)(see Chapter IV, 4.3).

Released DIP is returned to the upper layer by turn-over of the
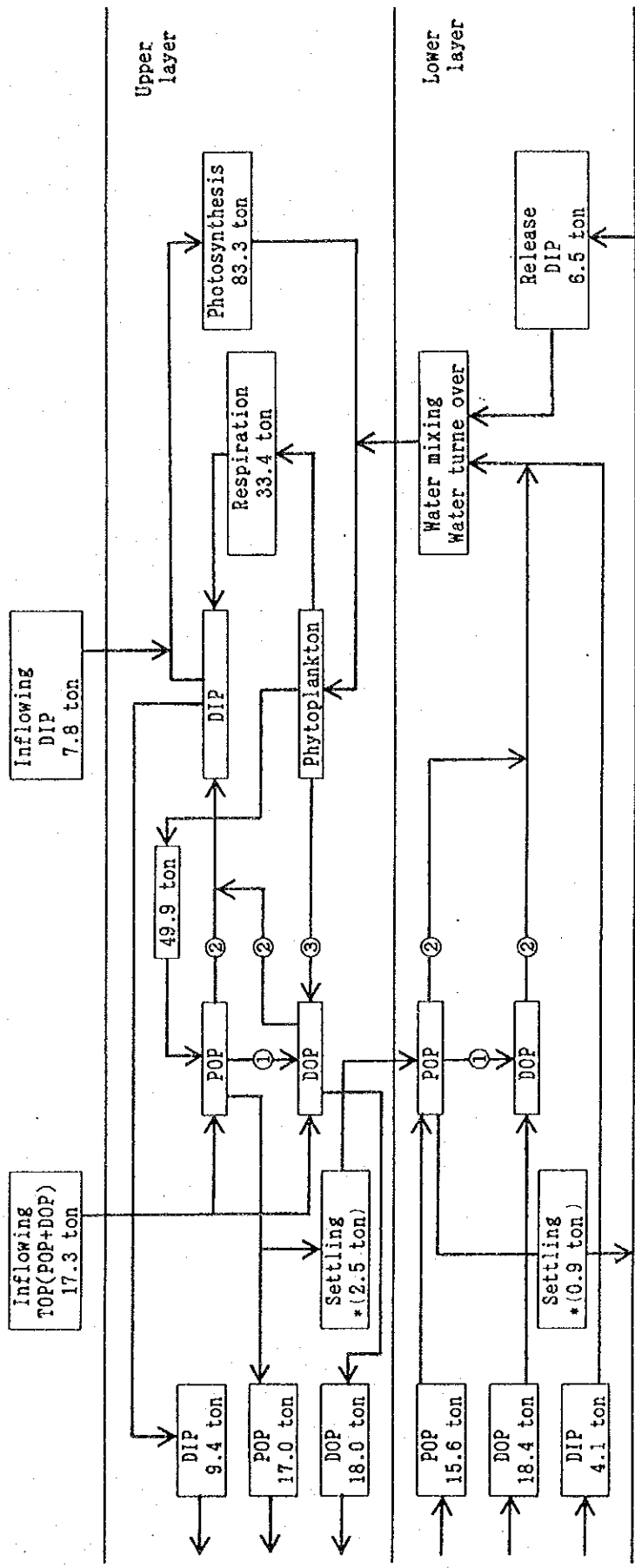
Fig.5.6-1 Phosphorus Cycle in the Dry Season
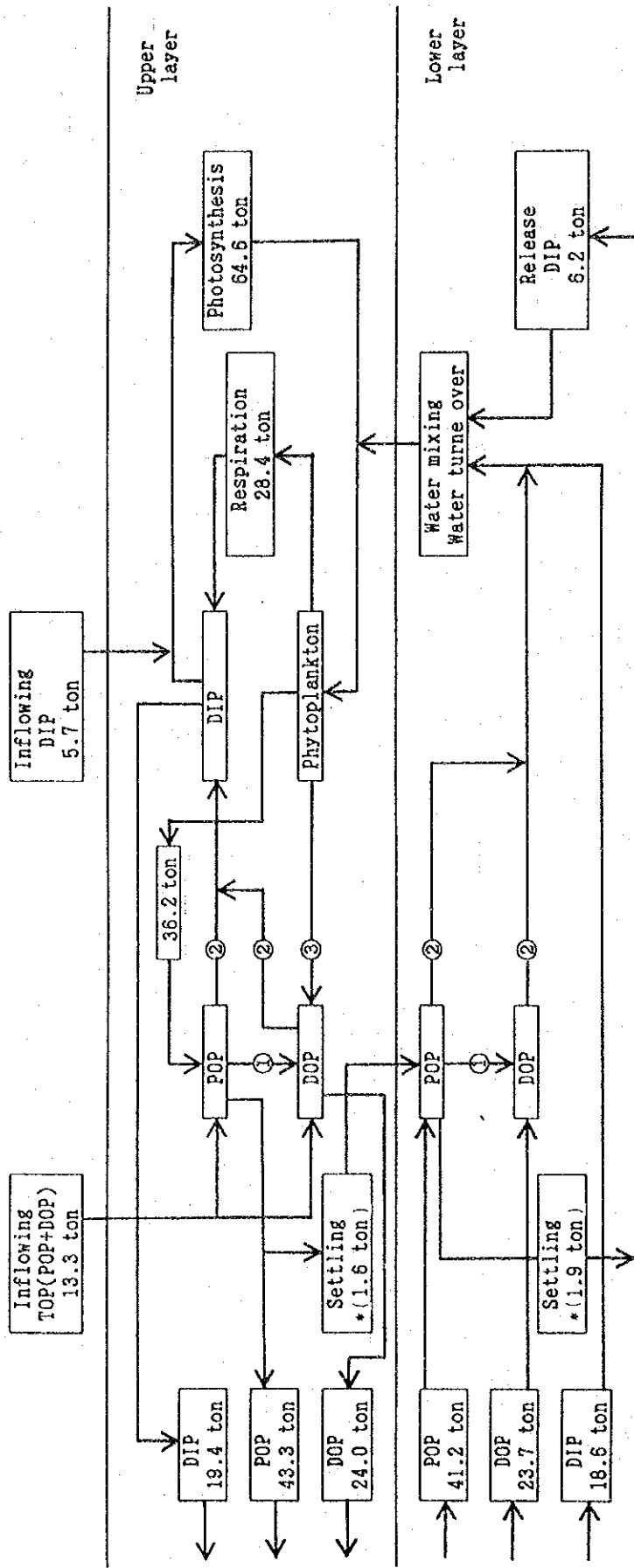
* The value of settling rate seems to be underestimated considering the values of release rate

① Decomposition
② Ionization
③ Extracellular production

Fig.5.6-2 Phosphorus Cycle in the Wet Season

* The value of settling rate seems to be underestimated considering the values of release rate

① Decomposition
② Ionization
③ Extracellular production

Table 5.6-1   Phosphorus Balance in the Dry Season in Sub-areas

Area		Jurujuba	Eastern	N-eastern	N-western	Western	Central	Botafogo	Entire Bay
Standing stock (ton)									
Upper layer	TP	4.5	3.9	18.6	36.2	25.4	36.4	3.2	128.2
	POP	-	1.8	10.6	10.8	6.2	9.2	0.8	39.4
	DOP	-	1.5	1.4	7.1	5.3	15.7	1.3	36.0
	DIP	0.8	0.6	6.6	18.3	13.9	11.5	1.1	52.8
Lower layer	TP	0.7	1.5	9.0	14.0	10.4	71.1	1.8	108.5
	POP	-	0.05	4.1	6.5	2.6	18.0	0.5	31.8
	DOP	-	1.25	0	0.3	0.9	25.3	0.5	28.8
	DIP	0.2	0.2	4.9	7.2	6.9	27.8	0.8	48.0
Additional									
Inflowing (ton/day)	TP	0.43	1.34	2.95	13.54	5.44	0.65	1.25	25.60
	TOP	0.29	0.79	1.92	9.38	3.61	0.43	0.86	17.28
	DIP	0.13	0.35	0.94	4.17	1.63	0.20	0.38	7.80
Respiration (37 %) (ton/day)	Day time	0.30	0.40	3.83	4.86	4.21	4.60	0.24	18.44
	Night time	0.25	0.33	3.10	3.94	3.41	3.73	0.20	14.96
	Total	0.55	0.73	6.93	8.80	7.62	8.33	0.44	33.40
Release (ton/day)	DIP	0.11	0.17	2.15	1.74	0.75	1.55	0.01	6.48
Exchange (in) (ton/day)	POP	0.48	0.73	1.69	1.64	2.57	8.13	0.39	15.63
	DOP	0.42	1.02	0.73	1.53	5.21	9.44	0.75	19.10
	DIP	0.39	0.15	0.48	0.00	0.10	3.02	0.00	4.11
Total additional (ton/day)	TOP	1.19	2.54	4.34	12.55	11.39	18.00	2.00	52.01
	DIP	1.18	1.40	10.50	14.71	10.10	13.10	0.83	51.82
Subtractive									
P-uptake (ton/day)	Gross-1	1.12	1.49	14.17	18.00	15.58	17.04	0.89	68.29
	Net	0.82	1.09	10.34	13.14	11.37	12.44	0.65	49.85
	Gross-2	1.37	1.82	17.27	21.94	18.99	20.77	1.09	83.25
Exchange (out) (ton/day)	POP	-	1.46	1.74	2.67	2.80	6.14	2.16	16.97
	DOP	-	1.08	1.67	1.45	2.80	10.26	3.46	20.72
	DIP	0.26	0.22	0.31	1.55	1.41	5.63	0.03	9.41
Settling (POP) (ton/day)	(%)	4.2	6.8	6.3	4.8	3.1	6.1	5.5	5.1
	1	0.034	0.074	0.651	0.631	0.352	0.759	0.036	2.54
	2	0.022	0.055	0.148	0.109	0.091	0.542	0.023	0.93
Total subtractive (ton/day)	POP	4.20	8.26	8.04	7.47	5.90	12.24	7.66	22.07
	DOP	-	1.08	1.67	1.45	2.80	10.26	3.46	20.72
	DIP	1.63	2.04	17.58	23.49	20.40	26.40	1.12	92.66
Balance-1 (ton/day)	DIP	-0.45	-0.64	-7.08	-8.78	-10.30	-13.30	-0.29	-40.84
Balance-2 (ton/day)	DIP	-0.95	-0.96	-9.71	-10.52	-11.15	-17.87	-0.30	-51.46
Expected decomposition or ionization rate (Time/day)	1	0.7	0.8	0.8	0.8	1.0	1.0	0.7	0.9
	2	1.1	0.9	1.0	0.9	1.0	1.2	0.7	1.0

Gross-1   : Gross P-uptake during a day
Gross-2   : Gross P-uptake during a day and at night
Settling-1 : Settling of POP produced by photosynthesis from the upper layer to the lower layer
Settling-2 : Settling of POP to the bottom in the lower layer which is settled from the upper layer and added
          by the water excahnge
Balance-1 : Released and exchanged DIP supplied to the upper layer by water mixing or turnover
          (Total Additional DIP - Total Substractive DIP)
Balance-2 : Neither released nor exchanged DIP
          (Inflowing DIP + Respired DIP - Total Substractive DIP)

Table 5.6-2   Phosphorus Balance in the Wet Season in Sub-areas

Area		Jurujuba	Eastern	N-eastern	N-western	Western	Central	Botafogo	Entire Bay
Standing stock (ton)									
Upper layer	TP	2.3	3.8	40.9	54.2	28.9	42.5	1.6	174.2
	POP	-	1.9	14.3	30.5	14.5	24.9	1.0	87.1
	DOP	-	1.5	22.9	16.1	6.0	10.8	0.1	59.3
	DIP	0.4	0.4	3.7	7.6	8.4	6.8	0.5	27.8
Lower layer	TP	2.3	1.2	44.2	79.7	23.6	109.7	1.4	262.1
	POP	-	0.5	6.8	45.9	9.1	39.4	0.6	102.3
	DOP	-	0.5	30.9	22.4	5.2	30.7	0.2	91.6
	DIP	0.6	0.2	6.5	11.4	9.3	39.6	0.6	68.2
Additional									
Inflowing (ton/day)	TP	0.32	0.87	2.35	9.63	3.85	0.55	0.86	18.43
	TOP	0.15	0.57	1.59	6.63	2.57	0.37	0.59	13.29
	DIP	0.10	0.26	0.71	2.98	1.18	0.17	0.26	5.66
Respiration (%) (ton/day)		65	58	58	52	51	40	65	
	Day time	0.33	0.61	5.16	2.31	2.45	6.49	0.16	17.52
	Night time	0.15	0.32	2.67	1.34	1.44	4.87	0.07	10.86
	Total	0.48	0.93	7.83	3.65	3.90	11.36	0.23	28.37
Release (ton/day)	DIP	0.12	0.17	1.90	1.84	0.68	1.41	0.05	6.17
Exchange (in) (ton/day)	POP	0.38	1.16	1.20	1.66	3.52	32.53	0.75	41.20
	DOP	0.08	0.05	1.10	3.02	2.17	16.30	1.00	23.72
	DIP	0.71	1.12	1.33	2.09	2.81	9.16	1.40	18.62
Total additional (ton/day)	TOP	0.61	1.78	3.89	11.31	8.26	49.2	2.34	78.21
	DIP	1.41	2.48	11.77	10.56	8.57	22.10	1.94	58.82
Subtractive									
P-uptake (ton/day)	Gross-1	0.88	1.67	14.06	6.76	7.26	22.72	0.40	53.75
	Net	0.50	1.06	8.90	4.45	4.81	16.23	0.24	36.19
	Gross-2	0.98	1.99	16.73	8.10	8.71	27.59	0.47	64.56
Exchange (out) (ton/day)	POP	-	1.60	6.80	12.61	9.92	9.94	2.54	43.41
	DOP	-	1.25	4.32	6.24	4.57	7.13	0.46	23.97
	DIP	0.76	0.25	3.33	2.21	2.97	8.52	1.32	19.36
Settling (POP) (ton/day)	(%)	8.4	6.9	7.8	2.4	2.8	4.5	2.8	4.5
	1	0.042	0.073	0.694	0.107	0.135	0.730	0.007	1.63
	2	0.035	0.035	0.148	0.042	0.102	1.497	0.021	1.93
Total subtractive (ton/day)	POP	0.04	1.67	6.95	12.65	10.02	11.44	2.56	45.34
	DOP	-	1.25	4.32	6.24	4.57	7.13	0.46	23.97
	DIP	1.74	2.24	20.06	10.31	11.68	36.11	1.79	83.92
Balance-1 (ton/day)	DIP	-0.33	0.24	-8.29	0.25	-3.11	-14.01	0.15	-25.10
Balance-2 (ton/day)	DIP	-1.16	-1.05	-11.52	-3.68	-6.6	-24.58	-1.3	-49.89
Expected decomposition or ionization rate (Time/day)	1	0.8		0.9		0.8	0.9		0.8
	2	2.3	1.0	1.1	0.9	1.2	1.2	2.3	1.2

Gross-1   : Gross P-uptake during a day
Gross-2   : Gross P-uptake during a day and at night
Settling-1 : Settling of POP produced by photosynthesis from the upper layer to the lower layer
Settling-2 : Settlin of POP to the bottom in the lower layer which is sttled from the upper layer and added by the water exchange
Balance-1 : Released and exchanged DIP supplied to the upper layer by water mixing or turnover
            (Total Additional DIP - Total Subtractive DIP)
Balance-2 : Neither released nor exchanged DIP
            (Inflowing DIP + Respired DIP - Total Subtractive DIP)

water, upwelling or vertical diffusion.

In the dry season, high wind velocities were not generally observed on the Bay, therefore, stratification is allowed to develop. It is difficult for released PO_4-P to returned to the upper layer.

While, in the wet season it may be returned by water mixing or turn-over, due to the occasional strong winds.

(4)   Settling Rate of particles

The settling rate of particles was measured using the indicators: TP, TKN and COD(Mn) (Chapter IV, 4.3). The rate of TP was adopted for POP rate here (Table APP 5.6-2).

The mean velocity of TP in the Bay is 0.132 m/day, which is 5.1 % of the total amount of particles settling a day for the dry and 4.5 % for the wet season.

5.6.2   Discussion

As shown in Table 5.6-1 and Fig. 5.6-1, the total amount of DIP to sustain only photosynthesis in the dry season (83.2 ton/day - Gross-2) is 31.4 ton/day more then the present available amount for production (51.8 ton/day - Total Additional DIP), although, released DIP from the bottom and exchanged DIP from outside of the Bay are included in the additional amount, they are only effective in the upper layer when there is water turnover or sustained water mixing.

However, wind velocity is often too weak in the dry season to produce water mixing or turn-over. Therefore, the deficit of P required to sustain the photosynthesis is usually around 51.5 ton/day (Balance-2).

The direct and indirect inflowing loads (7.8 ton/day) plays only a very small role in the total amount necessary for photosynthesis and others (92.7 ton/day - Total Subtractive DIP).

Many factors concerning the P cycle were not measured during this survey period, for example the decomposition rate from POP to DOP, the ionization rate from DOP to DIP and POP to DIP, extracellular production by phytopankton, grazing by zooplankton, excretion by zooplankton, the vertical diffusion rate and the stirring up of the bottom sediment, and the frequency and degree of water turn-over and mixing.

Of these factors, decomposition and ionization rate seem to have the most significant influence on the cycle.

When phosphorus is uptaken for net productivity it is simply considered to be transferred to POP, if the decomposition rate from

POP to DOP is about 1 time/day and all the DOP decomposes into DIP within a day, the P uptake by the present photosynthesis is sustained using again decomposed DIP.

This decomposition and ionization rate is very high but it may be possible.

For the wet season the same determination is considered (Table 5.6-2 and Fig. 5.6-2). The total direct and indirect inflowing loads of DIP (5.7 ton/day) are also too small to sustain the amount of DIP necessary (1.2 %). Although, the inflowing load through the rivers might be slightly underestimated because of the loss of phosphorus discharge by the first flush.

The amount of P uptaken by photosynthesis was also large. The deficit of P to sustain the total amount necessary is 25 ton/day (Balance-1) when released and penetrated P are included, otherwise it is 50 ton/day (Balance-2).

A decomposition and ionization rate of 0.8 to 1.2 times/day is necessary to sustain the P deficit.

In both seasons, a high uptake by photosynthesis, low inflowing loads and low contribution of release from the bottom were observed.

To sustain these P uptake very high decomposition and ionization rates need to exist. But, it is said extracellular production by phytoplankton is occasionally high (5 - 50 % of photosynthesis to DOP) and excretion by zooplankton also contributes in some degree.

In Guanabara Bay, the zooplankton biomass is always negligibly small, hence grazing and excretion can not be considered. However, extracellular production should be take into account in future considerations of the balance.

Similar conditions of P balance were found in all sub-areas in the dry season, consequently it lead to a similar balance over the entire Bay (Table 5.6-1).

The inflowing load by water exchange was small in the additional load, therefore, even when water mixing or turn-over does not occur and recovery from the lower layer is not found, the deficit amount was almost the same as that with recovery.

However, in all sub-areas high P uptake was found, hence a large amount of DIP is necessary to sustain photosynthesis.

While in the wet season, there was a sufficient DIP to sustain photosynthesis in the three sub-areas (E, NW and Botafogo), however, it was only just sufficient. It was, therefore, assumed that an equilibrium condition regarding P exists in these areas.

The organic matters directly flowing into the Bay or produced

within the Bay should also be considered.

277 ton/day of COD(Mn), which is one of the main organic parameters, is flowing directly into the Bay in the dry season (Table 5.5-1).

Using the conversion factor of 13.2 to convert POP to COD(Mn), which was obtained empirically from observation results, the gross and net productivity of COD(Mn) were estimated at 1099 ton/day and 659 ton/day, being about three and two times of the COD(Mn) inflowing amount.

While in the wet season, the inflowing COD(Mn)(383 ton/day) (Table 5.5-1) is larger than in the dry season, both gross and net productivity are smaller than in the dry season at 852 and 478 ton/day.

The conversion factor of 13.2 is a much smaller figure than what has been obtained in other areas (e. g. 34.7, 65.4 and 81 for planktonic COD/P in Tokyo Bay and Osaka Bay). This is because COD(Mn) was analyzed in this survey using alkaline methods which results in lower values than the ordinary COD(Mn) analysis method.

Presently in Guanabara Basin, the COD(Mn) produced by photosynthesis makes up the majority of organic pollution. Inflowing COD(Mn) is also important.

If the amount of additional organic matters produced by photosynthesis can be reduced accompanied with a reduction in the inflowing organic amount, it will be a major step towards lowering the levels of organic pollution in the Bay.

CHAPTER 6

SUBJECTS TO BE CONTINUED FOR PREVENTING THE FUTURE POLLUTION IN THE BAY

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Through the surveys several problems were found to be continued to prevent the future pollution regarding the water and sediment.

The water and the sediment in the Bay having already been seriously polluted accelerated the eutrophication. This condition causes the highly internal production in the entire Bay.

In particular it was observed that the very quick nutrients cycles in the water sphere mainly sustain the high internal production rather than the direct and indirect inflowing loads and released nutrients from the sediment in both seasons.

That is to say decomposition rate of particulate organic matters to dissolved organic one and ionization rates of particulate and dissolved organic matters to inorganic one are very high.

However, other many factors regarding production mechanism and material cycle in the Bay are still unknown, for examples they are exact internal production including respiration throughout the year, extracellular production, and grazing and excretion rates of zooplankton.

Besides, the extent of the stratification, frequency and the degree of water mixing or turnover to supply the nutrients from the deeper to the upper layers.

As also mentioned in Chapter V, it was found the several sub-areas exist where show the different characteristics of the water conditions and production mechanisms, and there are euphotic and decomposing layers in the entire of the Bay.

Meteorological conditions are changing every year, therefore, it is better to be considered of monthly variations on matters occurring in the Bay.

Subjects to be continued and its methods are below taking account of matters mentioned above.

General physical surveys and observations:

  1. Parameters
          Weather condition, salinity, water temperature, pH, DO and transparency

  2. Stations and areas
          At 15 stations surveys should be done (Fig.7-1).

3. Depth
        At the surface and the bottom, and intermediate
        several depths covering the euphotic depth,
        and discontinuous depths of physical parameters

4. Time and frequency
        At least once a month, if possible at the low
        and the high tides

Chemical surveys and observations on the water:

1. Parameters
        TN, PON, DON, TP, POP, DOP, DIP and *COD(Mn)

        *   Until time TOC of seawater will become to be well
            analyzed COD(Mn)-acidic method should be used.

            However, correlation with the values obtained
            by COD(Mn)-alkaline method and with BOD should be
            measured to compare the previous results.
            Even after the TOC will be analyzed, the correla-
            tions between the values obtained by COD(Mn)
            -acidic and TOC should be measured, because the
            same reason mentioned above.

2. Stations, areas, depths and frequency
        same as for the physical surveys

Biological surveys and observations:

1. Subjects to be measured
        Monthly variations of Chl-$\underline{a}$ concentrations
        with phytoplnakton and zooplankton species composi-
        tions and biomass

2. Stations and areas
        Same as physical and chemical surveys

3. Depths
        At the surface and the euphotic depths, and interme-
        diate depths

Subjects regarding production mechanism and material cycle:

1. Subjects to be measured
        Internal production (primary production) and unknown
        factors, especially decomposition and ionization
        rates

2. Stations and areas
        Measurements at 15 stations will be recommended. At
        least 8 stations to cover the entire of the Bay,

including Botafogo and Jurujuba Bays (Fig. 1).

'3. Depths
Surface and the exact euphotic depths, and intermediate depth to give the productivity in the euphotic layers

4. Time and frequency
At least in the dry and the wet seasons

Subjects regarding stratification and water mixing and turnover:

1. Subjects to be carried out
Extent of the stratification, frequency of water mixing and turnover with relationship to wind velocity

2. Station and areas
Particularly, in the areas where the stratification well develop; in the inner Bay area

3. Time and frequency
In the wet season the stratification developed and also the breakdown of it was frequently found, therefore, it should be done, more frequently in the wet season.

Surveys on the sediment:

Through the surveys, higher concentrations of heavy metals and chemical substances were observed in the sediment samples from the places near the river mouths and low current velocity, although the concentrations were not seriously high.

In future, however, in order to follow the change of the degree of the pollution, several surveys are recommended to be continued.

1. Concentrations of heavy metals and chemical substances should be measured occasionally at the places near the river mouths and low flow velocity.

2. It will be necessary to monitor the concentrations of heavy metals and chemical substances in edible fish and shellsifh, in particular for the species which highly concentrate these substances in their bodies through food chain.

3. It is also recommended to measure the release rates of the several parameters which are COD(Mn), BOD, TN, NH_4-N TP, PO_4-P and heavy metals near the river mouth areas with large flowing loads (Fig.6-1).
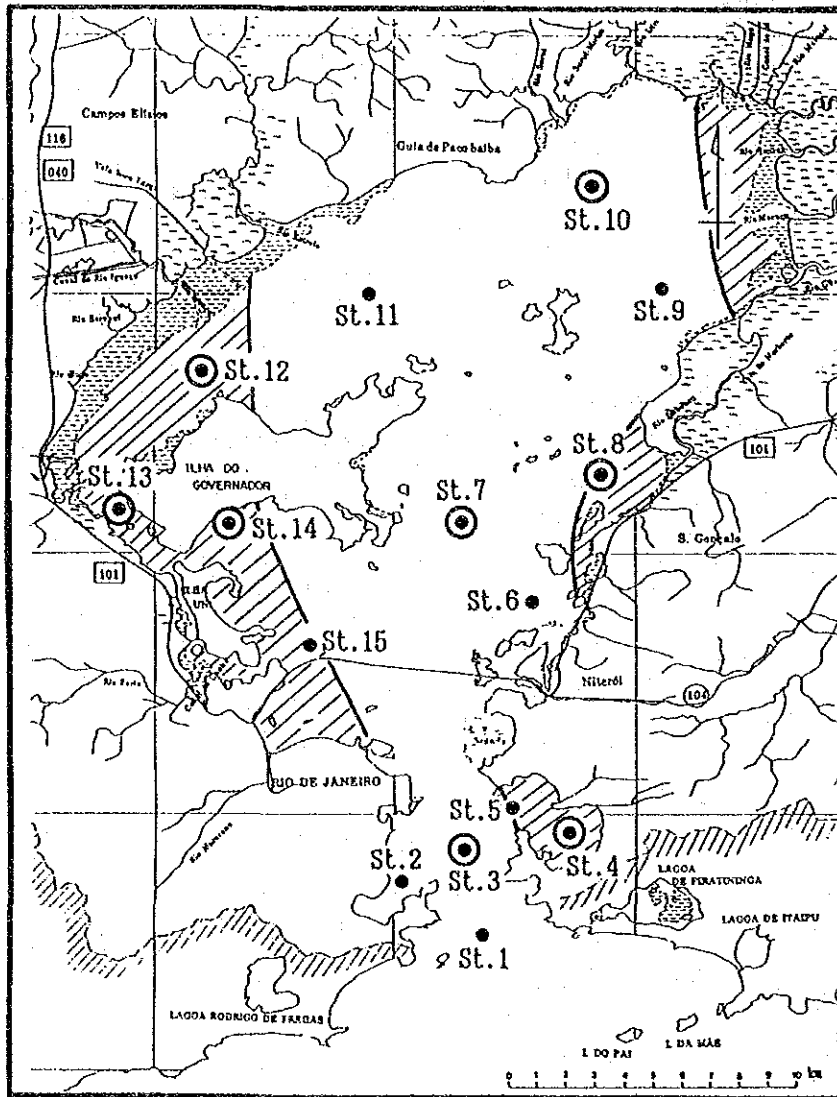
Fig. 6 – 1   Stations and Areas for Monitoring

St. 1 – St. 15 :   For general surveys

◉ :   For internal production measurements

⬛ :   For surveys on sediment

CHAPTER 7

AQUATIC ORGANISMS IN AND AROUND THE BAY

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AQUATIC ORGANISMS IN AND AROUND THE BAY

7.1 Water Quality Background

The development of the community of biological organisms in the ecosystem is fundamentally conditioned by the peculiar environmental characteristics of their habitat.

Some constituent elements of such an environment react complexly, resulting sometimes either in exaggerated proliferation or the extinction of groups of organisms, thus establishing the proper aquatic communities for each ecosystem.

Considering these facts, the physical and chemical behaviors observed can be summarized as follows, these being the key elements for the characterization of biological parameters of the Guanabara Bay.

According to the data base on pollution sources in the Guanabara Bay basin, heavy pollution sources proceeding from Rio Meriti, Rio Sarapui and Canal de Cunha, etc are being discharged to the western side of the bay enclosed by Ilha do Governador and Fundao.

Due to stagnation of water mass current in this area owing to narrow topographical conformation and great sludge accumulation, the discharged polluted matter tends to spread, partially to the southern and northern side of Ilha do Governador.

This modality of pollutants expansion is clearly underscored in Fig. 7.1-1, 7.1-2, 7.1-3, 7.1-4 that show the variation in nutrients and dissolved oxygen concentration, with mean values obtained from the 3 simultaneous surveys conducted in 1992.

High Ammonia concentration (0.6 to 1.3 mg/l) observed in water adjacent to Ilha do Governador gradually decreases toward the centre and entrance of the Bay, at a range of 0.05 to 0.1 mg/l, due to dilution, assimilation and the nitrification processes. The same expansion pattern was observed in TN and TP, thus sharp reduction in their concentrations were obtained near the entrance