Recovery of Aquatic Animals in Dokai Bay, Northern Kyushu, Japan

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Dokai Bay had been called a treasury area to catch Kuruma prawn; the catch from the bay reached a maximum in 1928. Aquatic animals, however, had been damaged by the untreated waste waters from Kitakyushu's heavy and chemical industrial area around the bay. The fishermen of Dokai Bay hadn't caught any fish since 1943, and from 1951 they were obliged to abandon their fishing rights of the inner and the middle parts of the bay. Such crushing damage from water polution atarted earlier than in other bays in Japan. Since then, due to the success to decrease the inflow of waste waters, the water quality of the bay was improved and commercial fishing of Kuruma prawn started again in 1983.

Since 1988, the presence of aquatic animals has been investigated with gill nets and a small trawling net. One hundred and fifteen species of aquatic animals: 65 species of fish, 37 species of Arthropoda, 12 species of Mollusca, and 1 species of Echinodermata were collected in there investigations. Almost all of them were coastal-temperate species, and some of them were the same species as those reported in the previous period. The species collected in abundance were: Kuruma prawn, Hardback shrimp, Mantis shrimp, Common goby, Streaked goby, Black porgy, and Gizzard shad. Aquatic animals collected were aboundant except in summer at the inner part of the bay where no biota zone had been found. Several species which had disappeared or were on the verge of extinction in 1933 were caught this time.

Marine organisms in Dokai Bay was unable to live because of the heavy water pollution due to the discharge of tremendous amounts of untreated domestic and industrial waste waters. This bay is unique because marine life damage started earlier, continued longer, and was damaged more seriously than in other Japanese bays. Recently however, we have observed several kinds of fish in the inner part of Dokai Bay. Dokai Bay, consequently, is a typical example of the return of marine organisms to a water environment upon improvement of the water quality.

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Since we have traced the succession of aquatic biota with the changing water quality in Dokai Bay and have investigated the present occurrence of aquatic animals, we wish to report the results.

Succession of aquatic animals

Fundamental aquatic biota in Dokai Bay was reported to have settled around five or six thousand years ago, when Old Dokai Bay had formed. Coastal marine species but not oceanic species were dominant and brackish species occurred together with them at the inner part of the bay. (Investigation Committee of Kurosaki Mound, 1981)

In more recent times, small scale fishing had been done in the bay by the fishermen from a few poor villages along the coastline of the bay. Old men have said that there had been catches of Eel, Common sea-bass, Black porgy, Striped mullet, Puffer, Oyster, Sea urchin, and particularly Kuruma prawn from the 1900's to the 1920's. There had been some seaweed beds which were used as growing places for different kinds of juvenile fishes. It has been said in the past that "Dokai Bay is a treasury area to catch Kuruma prawn". Kuruma prawn is one of the prime fishery products in Japan.

Government managed Yawata Steel Company started operations in 1901 along the coastline in the middle part of the bay, subsequently the Kitakyushu heavy and chemical industrial area around the bay was developed into one of the four biggest industrial areas in Japan. According to the "Report on the Investigation of Dokai Bay" (Fukuoka Prefectural Fisheries Experimental Station, 1933), the peak of catch in this bay was in 1928, then it decreased gradually due to the effects of water pollution on marine organisms. The catch in 1932 had decreased by one half of that in 1928. At the time seventeen species of aquatic animals had already disappeared or been on the verge of extinction. Bioassay had revealed the acute toxicity of waste waters which were discharged into Dokai Bay. Also, no biota zone had been found around Yahata Hakuchi, the middle part of the bay, by the watching and observation of marine organisms.

One year after this investigation,a large scale chemical plant was constructed on the coast line in the inner part of the bay. Thus, with industrial development, the water pollution of the bay had proceeded more and more rapidly in damaging the marine organisms (Fig. 1). According to the fishermen, the fouling organisms such as Oysters and Barnacles had been killed by water pollution and had fallen off within a few days after the entrance of Dokai Bay. Since 1943, the fishermen of Dokai Bay had caught nothing except for a few years immediately after the Second World War. The fishermen were obliged to abandon their fishing rights of Dokai Bay from the inner part to beneath the Wakato Bridge during 1951 and 1963. In the case of other bays of Japan including Tokyo Bay, marine life damage had appeared clearly before and after 1970 during the high economic growth period.

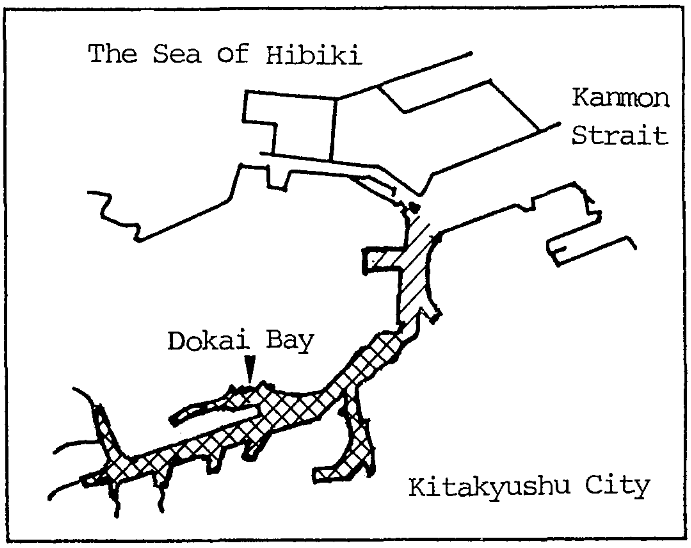

Fig. 1. Marine life damaged area in Dokai Bay from around 1943 to 1980 except for a few years immediately after the Second World War. Meshed area represents where fishermen caught nothing, and meshed and slant lined area shows where attaching organisms had not been observed. (According to the result of the hearing study about "Water Pollution and Occurrence of Aquatic Biota in Dokai Bay" with members of Wakamatsu Fishermen's Cooperative Association in February 1990).

Restoration of aquatic animals

Improvement of water quality and present condition of eutrophic level

By the strict enforcement of the water pollution control law in 1971, the water quality of Dokai Bay has improved rapidly, as all monitoring stations in the bay have achieved the Environmental Quality Standard from 1973 until now. Change of COD is shown in Fig. 2.

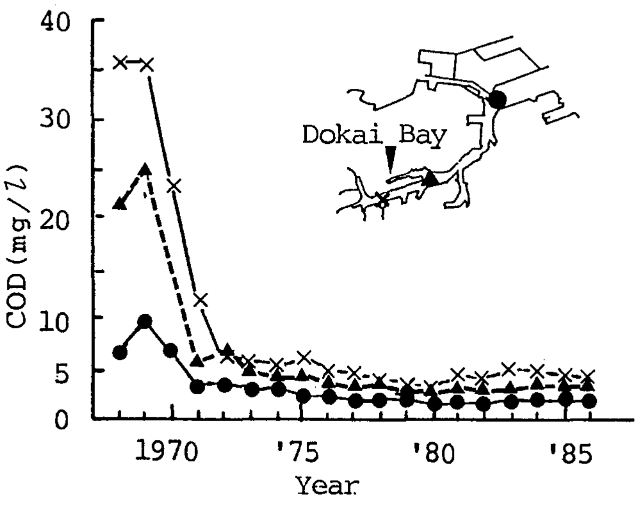

Fig. 2. Yearly changes of COD at three monitoring points in Dokai Bay from 1968 to 1986. Each value shows mean value of a year.

Plankton investigation has been done since 1974. The formation of red tide has been observed in every period when the water temperature is above 20° C. Representative red tide organisms in the bay are *Skeletonema costatum, Cyclotella striata* (diatoms), *Prorocentrum minimum* (dinoflagellta), unidentified blue-green algae, *Heterosigma akashiwo* (Raphidophyceae),and *Eutreptiella* sp. (Euglenophyceae).

By the application of a classifying method (Yamada et. al., 1980) of eutrophic levels of coastal water using phytoplankton occurrence data, Dokai Bay is judged to be an extremely eutrophic region, and this level has not changed during the past fifteen years. If we make additional remarks, this bay was classified as a suprobic region during the period from the latter half of the 1950's to the first half of the 1970's. The Sea of Hibiki which is connected with Dokai Bay is classified as an eutrophic region, the further offshore is supposed to be an oligotrophic region. It appears that the eutrophic level of Dokai Bay is still rather high, which means a lot of food (phytoplankton) is supplied for plankton feeder during the last 15 years.

Occurrence of aquatic animals

Commercial fishing of Kuruma prawn in Dokai Bay started again in 1983. The prawn catches were large enough for the fishermen to subsist. Aquatic animals in the bay, except Kuruma prawn , were not investigated after the improvement of water quality. We have begun to collect aquatic animals, which were caught by a Kuruma prawn gill net settled beneath Wakato Bridge since June 1988 (Fig. 3). Four times a year, once each season between May 1989 and January 1990, a qualitative investigation using a small trawling net and gill nets was done. Samples were collected at three points: the inner, the middle, and the outer parts of the bay (Fig. 3).

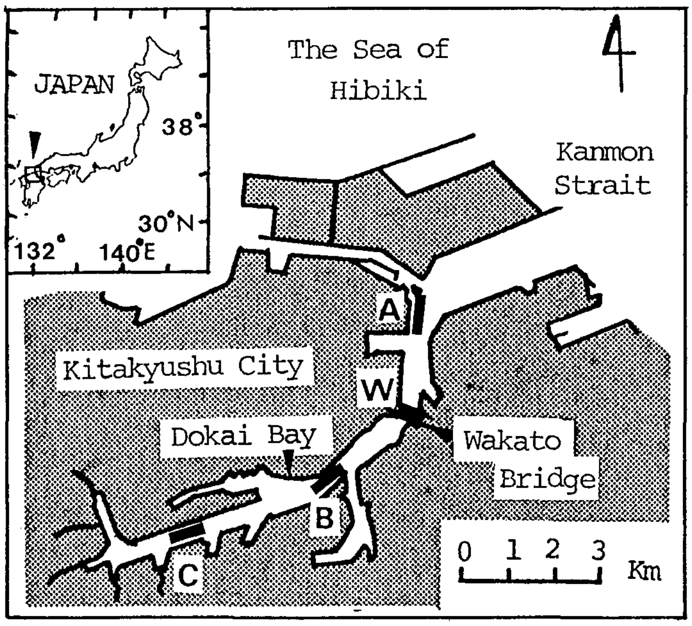

Fig. 3. Location map of collecting stations in Dokai Bay from June 1988 to January 1990. W,A,B, and C with black bars represent four collecting stations: beneath Wakato Bridge, the outer, middle and inner parts of the bay.

In these investigations about one hundred and fifteen (115) species of aquatic animals were collected as shown in Table 1: sixty five (65) species of fish, thirty seven (37) species of Arthropoda, twelve (12) species of Mollusca, and one (1) species of Echinodermata . Almost all of them are coastal and temperate species, and some of them are the same species as those reported in the period before the marine life damage. Samples collected with the gill net beneath Wakato Bridge include: Horse shoe crab *Tachypleus tridentatus* which has been designated as a precious natural species due to the recent decrease of their numbers. Prime species: Tiger puffer *Takifugu rubripes*, Flounder *Paralichthys olivaceus*, and Rockfish *Sebastes inermis* were collected with it. Tiger puffer had been released from Hikoshima, Yamaguchi prefecture, located on the opposite side of Kanmon Strait.

Comparing present species with those in 1933, commercial values of Mantis shrimp *Squilla oratoria* and Oyster *Crassostrea gigas* had been low due to oil odor and green coloration respectively. These problems now are not found. Black porgy *Acanthopagrus schlegeli*, Silver bream *Sparus sarba*, and Cuttlefish *Sepia esculenta* were collected now, nevertheless they had disappeared or had been on the verge of extinction in 1933.

In the present, Kuruma prawn *Penaeus japonicus*, Hardback shrimp *Trachypenaeus cuvirostris*, Mantis shrimp, Common goby *Acanthogobius flavimanus*, Streaked goby *Acentrogobius pflaumii*, Black porgy, and Gizzard shad *Konosirus punctatus* were the predominant species at the inner part of the bay, where no biota zone had been found. Catch weight there decreased markedly in summer and increased in winter. The inner part of the bay in particular was supposed to be used as the spawning ground of Common goby in winter.

Short-necked clam *Ruditapes philippinarum* collected from the very narrow tidal land along the bay was found to take *P. minimum* which was red tide organism at the time. Rock trout *Hexagrammos otakii* collected with a small trawling net at the inner part of the bay was also found to eat the small shrimp *Palaemon macrodactylus* which was collected with it. The contents of the stomach in several fishes collected in spring were Japanese opossum shrimp *Neomysis japonica* which were collected using a larva fish net in the same investigation. The Japanese opossum shrimp was observed with the appearance of both adult and larval forms together, the occurrence of which shows the reproduction of food for zooplankton feeder in the bay.

Discussion and Conclusions

These time investigations of aquatic animals reveal that species that had once disappeared have recovered. Several kinds of species were observed to have better appearances than those in 1933. The aquatic animals have been caught throughout the bay, except at the inner part of the bay during the summer. Many fish have been caught in this once fishless region. Small parts of the food chain were found to exist in the bay: between phytoplankton and shell, macro zooplankton and fish, and benthos and fish.

Table 1. Aquatic animals collected from Dokai Bay from June 1988 to February 1990

MOLLUSCA (12species)
GASTROPODA
Notoacmea concinna (Lischke)
Rapana venosa (Valenciennes)
Balylonia japonica (Reeve)
Hemifusus tuba (Gmelin)
BIVALVIA
Chlamys farreri (Jones et Preston)
Crassostrea gigas (Thunberg)
Ruditapes philippinarum (A. Adams et Reeve)
CEPHALOPODA
Sepia lycidas Gray
S. esculenta Hoyle
Sepiella japonica Sasaki
Euprymna morsei (Verrill)
Loligo sp.

ARTHROPODA (37species)
XIPHOSURA
Tachypleus tridentatus Leach
CRUSTACEA
Mysidaceae
Neomysis japonica Nakazawa
Decapoda
Macrura
Metepenaeopsis acclivis (Rathbun)
Metapenaeus ensis (De Haan)
M. joyneri (Miers)
Parapenaeopsis tenella (Bate)
Penaeus japonicus Bate
Trachypenaeus curvirostris (Stimpson)
Acetes japonicus Kishinouye
Alpheus distinguendus De Man
A. japonicus (Miers)
Crangon affinis (De Haan)
Lysmata vittata (Stimpson)
Palaemon macrodactylus Rathbun
P. serrifer (Stimpson)
P. ortmanni (Rathbun)
Anomura
Upogebia major (De Haan)
Raphidopus ciliatus Stimpson
Porcellanidae gen. et sp. indet.
Dardanus sp.
Brachyura
Dorippe japonica Von Siebold
D. dorsipes (Linné)
Myra fugax (Fabricius)
Leucosia longifrons De Haan
Majidae gen. et sp. indet.
Lambrus validus De Haan
Cancer sp.
Portunus trituberculatus (Miers)
P. pelagicus (Linné)
P. hastatoides Fabricius
Charybdis japonica A. Milne-Edwards
C. bimuaculata (Miers)
C. truncata (Fabricius)
Carcinoplax vestitus (De Haan)
Eucrate crenata De Haan
Eriocheir japonicus (De Haan)
Stomatopoda
Squilla oratoria De Haan

ECHINODERMATA (1species)
ASTEROIDEA
Asterias amurensis Lütken

VERTEBRATA (65species)
CHONDRICHTYES
Dasyatis akajei (Müler et Henle)
Gymnura japonica (Temminck et Schlegel)
OSTEICHTHYES
Sardinops melanostictus (Temminck et Schlegel)
Sardinella zunasi (Bleeker)
Konosirus punctatus (Temminck et Schlegel)
Engraulis japonicus (Houttuyn)
Conger myriaster (Brevoort)
Pisodonophis zophistius Jordan et Synder
Plotosus lineatus (Thunberg)
Saurida elongata (Temminck et Schlegel)
Hyporhamphus sajori (Temminck et Schlegel)
Mugil cephalus cephalus Linnaeus
Lateolabrax japonicus (Cuvier)
Epinephelus akaara (Temminck et Schlegel)
Apogon lineatus (Temminck et Schlegel)
Sillago japonica Temminck et Schlegel
Trachurus japonicus (Temminck et Schlegel)
Leiognathus nuchalis (Temminck et Schlegel)
Lobotes surinamensis (Bloch)
Nibea mitsukurii (Jordan et Snyder)
Argyrosomus argentatus (Houttuyn)
Upeneus bensasi (Temminck et Schlegel)
Girella punktata Gray
Lutjanus vitta (Quoy et Gaimard)
Parapristipoma trilineatum (Thunberg)
Plectorhynchus cinctus (Temminck et Schlegel)
Rhyncopelates oxyrhynchus (Temminck et Schlegel)
Pagrus major (Temminck et Schlegel)
Sparus sarba (Forsskål)
Acanthopagrus schlegeli (Bleeker)
Oplegnathus fasciatus (Temminck et Schlegel)
Ditrema temmincki Bleeker
Trichiurus lepturus Linnaeus
Siganus fuscescens (Houttuyn)
Psenes cyanophrys Valenciennes
Pampus argenteus (Euphrasen)
Acentrogobius pflaumii (Bleeker)
Tridentiger trigonocephalus (Gill)
Acanthogobius flavimanus (Temminck et Schlegel)
Amblychaeturichthys hexanema (Bleeker)
Leucopsarion petersi Hilgendorf
Parapercis sexfasciata (Temminck et Schlegel)
Petroscirtes breviceps (Valenciennes)
Sebastes inermis Cuvier
S. shlegeli Hilgendorf
Inimicus japonicus (Cuvier)
Hypodytes rubripinnis (Temminck et Schlegel)
Hexagrammos otakii Jordan et Starks
Suggrundus meerdervoorti (Bleeker)
Platycephalus indicus (Linnaeus)
Lepidotrigla abyssalis Jordan et Starks
Repomucenus huguenini (Bleeker)
R. richardsonii (Bleeker)
Paralichthys olivaceus (Temminck et Schlegel)
Pseudorhombus pentophthalmus Günther
Pleuronichthys cornutus (Temminck et Schlegel)
P. yokohamae Günther
Kareius bicoloratus (Basilewsky)
Stephanolepis cirrhifer (Temminck et Schlegel)
Rudarius ercodes Jordan et Fowler
Takifugu xanthopterus (Temminck et Schlegel)
T. rubripes (Temminck et Schlegel)
T. niphobles (Jordan et Snyder)
T. vermicularis (Temminck et Schlegel)
Lagocephalus gloveri Abe et tabeta

Currently marine environmental problems of Dokai Bay have shifted from serious organic and heavy metal pollution to eutrophication within the last twenty years. Recently, chemical substances have been detected from sediment in the bay (Hanada et. al., 1989). It is necessary to study the effects of chemical substances on marine organisms (Kinae, 1988), as well as on the human body, because aquatic animals are now making a comeback in the bay.

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A great number of dates and literature were referred to in this paper, space however did not permit us to mention them.

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