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Summer Oxygen Deficiency and Benthic Biomass in the Chinhae Bay System, Korea

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1983년 鎭海灣 一帶 海域의 여름철 底層 溶存酸素의 缺乏과 底棲生物量과의 關係

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Abstract

Quantitative benthic invertebrate samples were taken in the Chinhae Bay System, Korea during September 1983 to relate benthic biomass to bottom water dissolved oxygen concentrations. Low concentrations of bottom water dissolved oxygen were found to be associated with low benthic biomass and abundance. Benthic biomass(wet weight) and animal numbers decreased logarithmically with bottom dissolved oxygen concentrations. A hypoxic bottom area(≤ 2.0 *ml/l*, 40% oxygen saturation) extended over most of the bay, covering an area of about 266km^2, out of a total of 497km^2. The most affected areas were limited, as a whole, to inner areas of Masan and Haeng-am Bays, Kohyonsong Bay, Wonmunpo Bay, and the Chinhae Bay Proper.

요약 : 鎭海灣 一帶 海域에서 夏季 底層 溶存酸素의 缺乏 현상과 底棲生物量과의 關係를 밝히기 위하여 1983年 9月 底棲生物의 生態學的 調査를 실시하였다. 일반적으로 底層의 溶存酸素量이 낮은 地域에서는 底棲生物量과 個體數가 현저히 감소하였다. 底層의 溶存酸素量이 2.0*ml/l*이하 그리고 酸素飽和度 40% 이하인 貧酸素 海域이 전체 調査海域 497km^2의54%를 차지하는266km^2에 걸쳐 광범위하게 발달하고 있음이 밝혀졌으며, 특히 馬山灣, 行岩灣, 古縣城灣, 加助島 西側의 元門灣, 鎭海灣 中央部 등이 영향을 받는 것으로 나타났다.

INTRODUCTION

The hypoxia and anoxia have serious effects on bottom water chemistry and the benthic community, especially in areas where the bottom water alternates between oxic and anoxic conditions. The transport of oxygen to the bottom is governed primarily by hydrological conditions in a given area, particularly by the stability of stratification in the water column. In many badly ventilated semi-closed or entirely closed bays there is a seasonally cyclic phenomenon of this oxygen deficiency in the bottom water. Low oxygen concentrations are usually reached during the summer when temperature or salinity stratification persists and the benthic and water column biological oxygen consumption are maximum.

Under this stagnation and oxygen-deficient bottom waters, macrofaunal biomass often shows a significant positive correlation with oxygen concentration, and can be regulated by periodic mass mortalities and

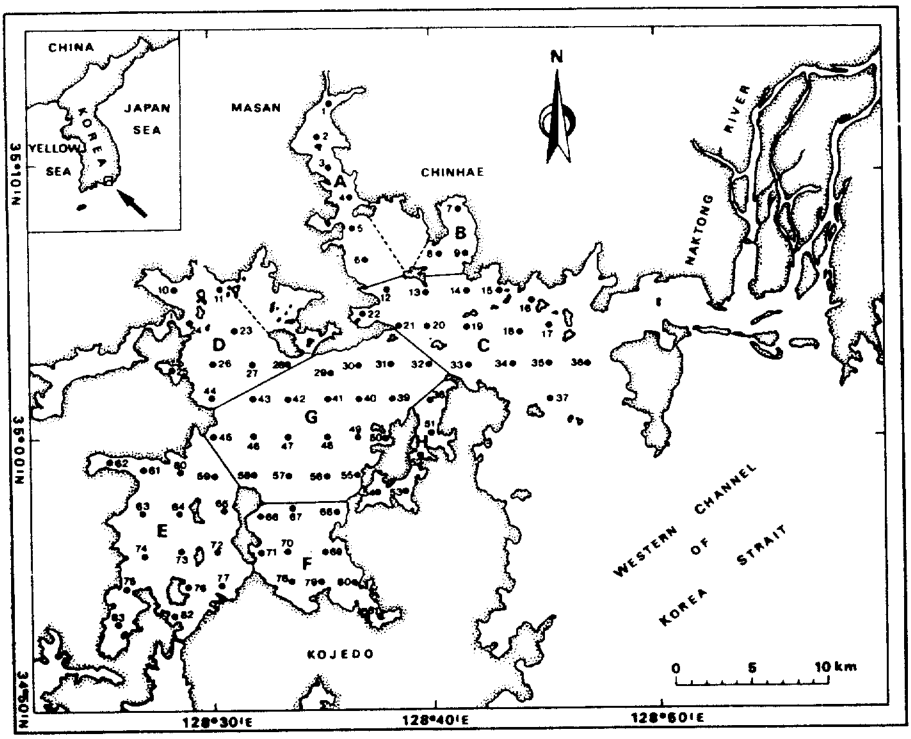

Fig. 1. Study area in the Chinhae Bay System with stations and eight subareas indicated: A=Masan Bay, B=Haeng-am Bay, C=Kadok Waterway, D= Chindong Bay, E=Wonmunpo Bay, F=Kohyonsong Bay, G=Chinhae Bay Proper, and H=Chilchon Waterway.

recolonizations (Jorgensen, 1980). These sequences may take place annually, following a seasonal rhythm. Then sporadic mortalities of demersal fishes and benthic macro-invertebrates due to anoxia are common in various parts of the worlds (Brongersma-Sanders, 1957; Loesch, 1960; Tulkki, 1965; May, 1973; Garlo *et al.*, 1979; Steimle & Radosh, 1979; Jorgensen, 1980).

Recently domestic and industrial wastes have been determined to be primary causes of marine pollution problems in the Chinhae Bay System, south-eastern Korean Peninsula, including "red tides" which occur very frequently in this coastal area. Several previous studies have examined water quality (KORDI, 1981), phytoplankton community (Yoo and Lee, 1979, 1980 a, 1980 b; Park, 1980, 1982), and sediments of shell-fish farms in Chinhae Bay complex (Cho *et al.*, 1982). However, little is known of the benthos in the Chinhae Bay System, although Hong and Lee (1983) have studied benthic samples from a limited northeast portion of the Chinhae Bay System. Consequently the benthos of the Chinhae Bay System remains poorly known, while previous oceanographic studies, concentrated on the causative organisms of "red tide", has received much attention due to the increasing industrial development in the surrounding periphery of the bay complex. The objective of this preliminary study is to describe the occurrence and extent of hypoxia and its relationship to benthic biomass during a hypoxic period (September 1983) in the Chinhae Bay System.

MATERIALS AND METHODS

Description of the Chinhae Bay System

The Chinhae Bay System is situated in the southeastern part of the Korean Peninsula (Fig. 1). It is composed of eight major subareas : Masan Bay, Haeng-am Bay, Kadok Waterway, Chindong Bay, Wonmunpo Bay, Kohyonsong Bay, Chinhae Bay Proper, which is the central part in Chinhae Bay System, and Chilchon Waterway. The total area surveyed is approximately 497 km^2. The eastern boundary of the bay complex is the connection with the western channel of the Korea Strait and influenced by freshwater inflow from the nearby Naktong River. Wonmunpo Bay forms the southeasterly boundary at one small opening, Kyonnaeryang Pass, that also connects to Tongyonghae Bay and other southern Korean coastal waters.

This bay complex has been an important spawning and nursery grounds for many commercially important fishes, and also recently supported high shellfish production, e.g. intensive raft or long line culture of oysters (*Crassostrea gigas*) and mussels (*Mytilus edulis*), and by bottom culture for ark shell (*Scapharca broughtonii*). A total of 37.5 km^2 is actually used for aquaculture in this area, which is approximately 7.5% of the Chinhae Bay System.

However, it should be noted that Masan Bay, Haeng-am Bay, and adjacent areas have frequently-occurring dinoflagellate caused red tides and are heavily contaminated by organic domestic wastes and other wastes from very diverse industrial activities, including pulp mills, textile, food and drink industries, and by the heavy metals from the Chang-won industrial complex (KORDI, 1980, 1981). The distribution of soft-bottom macrobenthos in Masan Bay showed also lower species richness and numerical abundance than those of other similar Korean coastal habitats (Hong and Lee, 1983).

The Chinhae Bay System is 45 *m* deep near its connection to western channel of Korea Strait but averages 20 *m* in depth. Mean tidal range is 2.0 *m*, and annual prevailing winds are generally southwest. Seasonal ranges in salinity and temperature are large (KORDI, 1983) : based on the monthly data collected in 1983, surface-water temperatures annually range from 4.4 to 27.7℃ with bottom temperature at 3.9 to 26.3℃. Surface salinity ranges from 7.0 to 33.45‰ with bottom salinity at 29.0 to 33.85‰. Percent saturation of dissolved oxygen in surface waters ranges from 63% to 196%. Water transparency varies greatly from 0.5 to 14.5 *m*, but it is generally lowest in the summer and in Masan Bay, and highest in the winter and in Chinhae Bay Proper. Sediments are composed mostly of silt, but gravel and fragmented molluscan shells are found in areas of relatively strong currents, e.g. the sill located at the entrance of Masan Bay and the southeastern part of the Kadok Waterway (Hong and Lee, 1983 ; personal observation).

Sample collection and data analysis

The samples for this study were collected during a survey cruise on the oceanographic vessel BANWOL-HO of Korea Ocean Research and Development Institute between September 8 to September 16, 1983. Eighty three stations were selected with a grid interval of 2.5 *km* and sampled (Fig. 1).

Temperature and salinity were recorded by using an Oceanographic Salinity and Temperature Measuring Bridge (Type MC 5). Dissolved oxygen measurements were determined with a YSI Model 57 dissolved oxygen meter. Dissolved oxygen saturation percentages were calculated according to Weiss(1970).

Five replicate benthic samples were taken at each station with a 0.1 m^2 Van Veen grab and sieved through a 1 mm mesh screen. Macrobenthic faunal biomass data were obtained by blotting all individuals of each species on absorbent paper for approximately three minutes at room temperature and then weighing on an electronic balance. The wet weights included molluscan shells which were opened to drain surficial fluids, but not tubes of polychaetes and crustaceans. The logarithmic transformation $\log_{10}(x+1)$ was used for the benthic biomass and abundance data to execute least squares regression analysis.

RESULTS AND DISCUSSION

The role of dissolved oxygen in determining the distribution of benthic fauna in estuarine or coastal waters has been discussed often in the literature. Low oxygen concentrations have been recorded from various parts of the world oceans and extensive mortality of bottom organisms and fishes have been frequently reported(Kikuchi and Tanaka, 1978 ; Steimle and Radosh, 1979 ; Garlo *et al.*, 1979 ; Jorgensen, 1980 ; Rosenberg, 1980 ; Dethlefsen and von Westernhagen, 1983 ; Dyer *et al.*, 1983 ; Tsutsumi and Kikuchi, 1983).

In fjords of northwest Europe, benthic biomass and abundance have been found to decrease drastically when the oxygen concentrations drop below 0.3 to 1.0 *ml/l* (Rosenberg, 1980). In an ecological study of pollution in Los Angeles-Long Beach Harbors, Reish(1959) concluded that the dissolved oxygen content of the water mass and the distribution of the bottom-dwelling animals were of the greatest use as indicators of water quality. Therefore, the distribution of the macrobenthic animals is of particular value since it reflected the water conditions for some time prior to sampling.

Tsutsumi and Kikuchi(1983) reported in a small semi-enclosed bay on the west coast of Kyushu, Japan that the local benthic defaunation during the period of summer stratification was caused by the severe oxygen depletion in the bottom water and the accumulation of sulphide in the sediment. In addition, it should be noted that the formation of azoic zones in a closed or semi-closed bays is closely related to the sulphide content of the sediment(Nakao, 1978). Hydrogen sulphide(H_2S) is produced by the metabolism of sulphate-reducing bacteria which are activated under hypoxic conditions.

Distribution pattern of bottom oxygen concentrations

The geographical distribution of dissolved oxygen levels of the bottom waters during September 1983 in the Chinhae Bay System is shown in Figure 2. In general, bottom water dissolved oxygen levels were low and ranged from 0.11 to 4.49 *ml/l* with a mean of 2.05±1.08 *ml/l*. Dissolved oxygen concentrations in bottom waters were almost depleted(<1.0 *ml/l*) in three inner bays subareas(A, B, F). This nearly oxygen depleted area, where hydrogen sulfide was also observed at some stations, covers about 66 km^2, which is about 15% of the total area studied. Oxygen concentrations tended to increase at the main entrance of the Chinhae Bay System, the Kadok Waterway area. Bottom oxygen levels progressively declined toward inner bay areas including most of subareas A, B, and F and parts of others, e.g. D, E, and G(Fig. 2).

Studies of Chemical Oxygen Demand(C.O.D.) and phaeophytin content of the superficial bottom mud(Cho *et al.*, 1982) indicat-

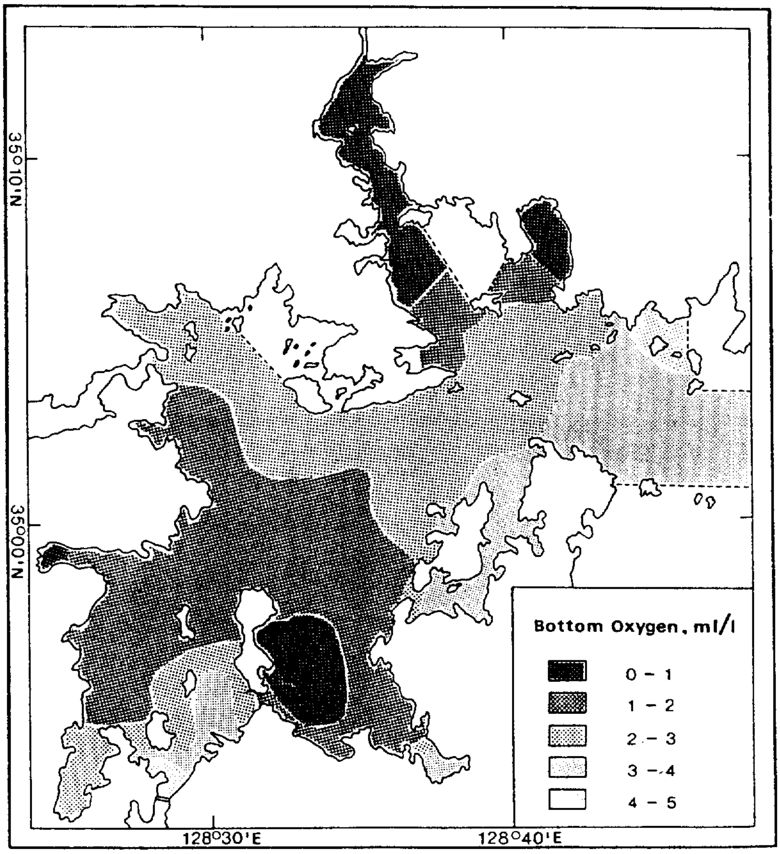

Fig. 2. September 1983 distribution of bottom dissolved oxygen concentrations(*ml/l*) in the Chinhae Bay System.

ed that the most organically polluted zones were localized in the Wonmunpo and Kohyonsong Bays(subareas E and F). This is in fairly good agreement with our macrofaunal biomass and abundance data, even though C.O.D. and phaeophytin information for other areas, including Masan and Haeng-am Bays, of our study area were unfortunately not available. The region of hypoxia(1.0 – 2.0 *ml/l*) appeared to affect a wide area, of approximately 200 km^2, 40% of the total surveyed area. Thus, although surface waters generally remained well-oxygenated, bottom water oxygen concentration fell below 2.0 *ml/l* over an area of 266 km^2, almost 55% of the total study area. Bottom oxygen levels in outer bay subareas(C, H) were higher, 2.5 to 4.49 *ml/l*.

Oxygen saturation of the bottom waters ranged from 2.1% to 88.8% with a mean of 39.9±21.1% and much of the bay system were influenced by hypoxically undersaturated oxygen(<40%) bottom waters. It showed the same distribution pattern as the bottom oxygen concentrations.

Benthic biomass and abundance

Biomass of benthic macrofauna in the study area was found to range between 0 to 2034.14 g/m^2 with a mean of 150.909± 335.886 g/m^2. The biomass distribution data(Fig. 3) suggest that the portions of the study area with oxygen concentrations

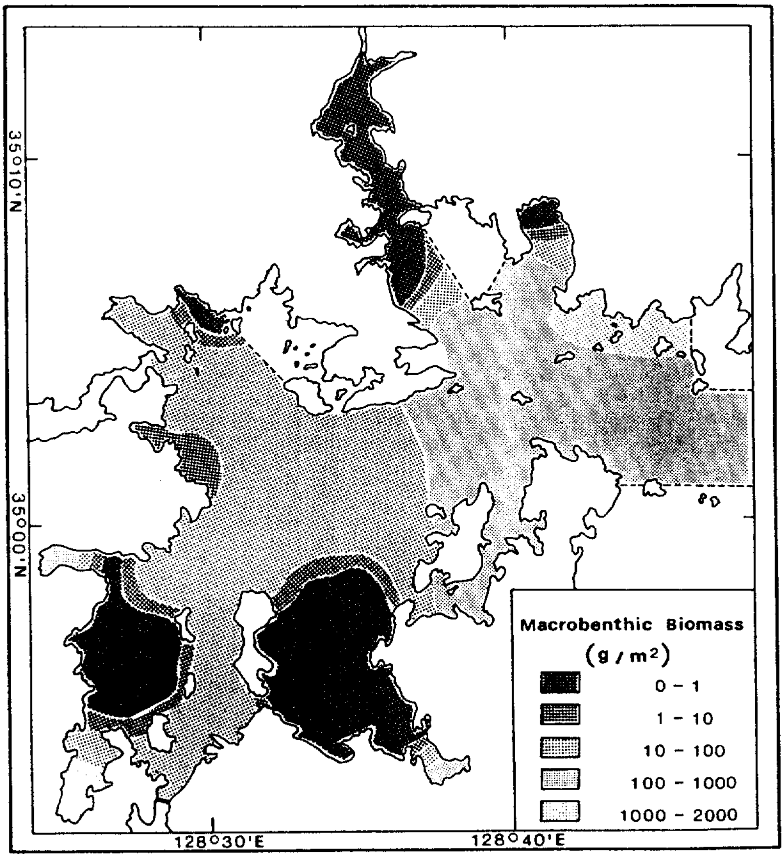

Fig. 3. Septmeber 1983 distribution of macrobenthic biomass(wet weight, g/m^2) in the Chinhae Bay System.

below 1 ml/l are azoic or have macrofaunal biomass of less than 1 g/m^2. This was generally in the more stagnated inner bays subareas(A, B, E and F). Figure 3 shows that higher biomass levels above 100 g/m^2 are limited to subareas C and H, which are influenced by outer bay oxygenated waters.

The macrobenthic abundance ranged between 0 to 6220 individuals/m^2 with a mean of 1441±1757 individuals/m^2. The spatial distribution of macrofaunal densities was congruent with that of benthic biomass (Fig. 4). The lowest biomass zones, with less than 1 g/m^2, were quite similar to those of the lowest benthic invertebrate abundances, with a density of less than 10 individuals/m^2. Macrobenthic densities were relatively high only in the areas under the influence of outer bay water(subareas C, H, G in part, and Kyonnaeryang Pass) with a density of more than 1000 individuals/m^2.

However, it should be noted that both biomass and abundances are usually low during hypoxic periods so that the present biological data are not good estimates of the areas annual mean.

Bottom oxygen concentration to benthic biomass relationships

The macrobenthic biomass data are plotted against oxygen concentrations in Figure 5. The distribution of bottom oxygen concentrations was correlated with those of

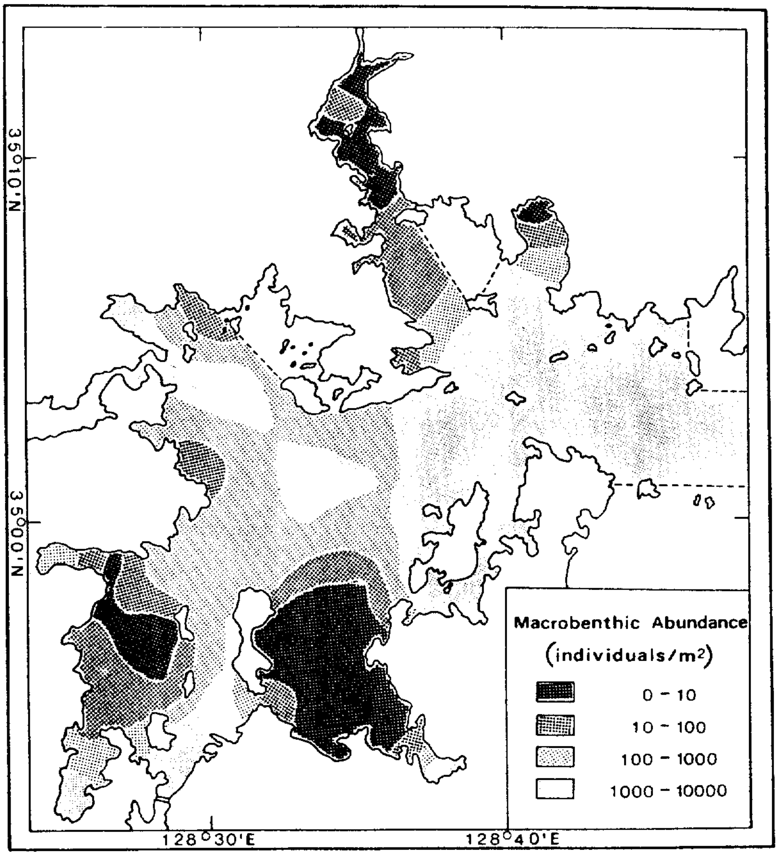

Fig. 4. Septmeber 1983 distribution of macrobenthic abundance(individuals/m^2) in the Chinhae Bay System.

macrobenthic abundance($r = 0.76$) and biomass($r = 0.72$). Least squares regressions of the logarithm(base 10) of benthic invertebrate biomass and abundance data on bottom oxygen concentrations indicated that biomass and animal numbers increased according to the following relationships,

$$\mathrm{Log}_{10}\ \text{Wet Weight}(g/m^2) = 0.0462 + 0.6687 \cdot O_2(ml/l)$$

and

$$\mathrm{Log}_{10}\ \text{Animals}(\text{individuals}/m^2) = 0.7991 + 0.8024 \cdot O_2(ml/l)$$

respectively.

The cause of low benthic biomass in portions of the Chinhae Bay complex in September 1983 is probably low dissolved oxygen concentrations in bottom waters and poisoning by hydrogen sulfide(H_2S) generation at anoxic levels. However, according to Lee and Lee(1983) from the sediment samples collected in September 1982, the concentrations of some trace metals such as Cd, Cr, Cu, Pb, and Zn are particularly high in the inner part of Masan Bay, but they decreased gradually with increasing distance from the head of Masan Bay, indicating that those metals were highly affected by industrial and municipal wastewaters entering into the bay. Then this information may suggest that only the inner portion of Masan Bay affects the mortality of benthic invertebrates or low levels of benthic biomass by these trace metals as

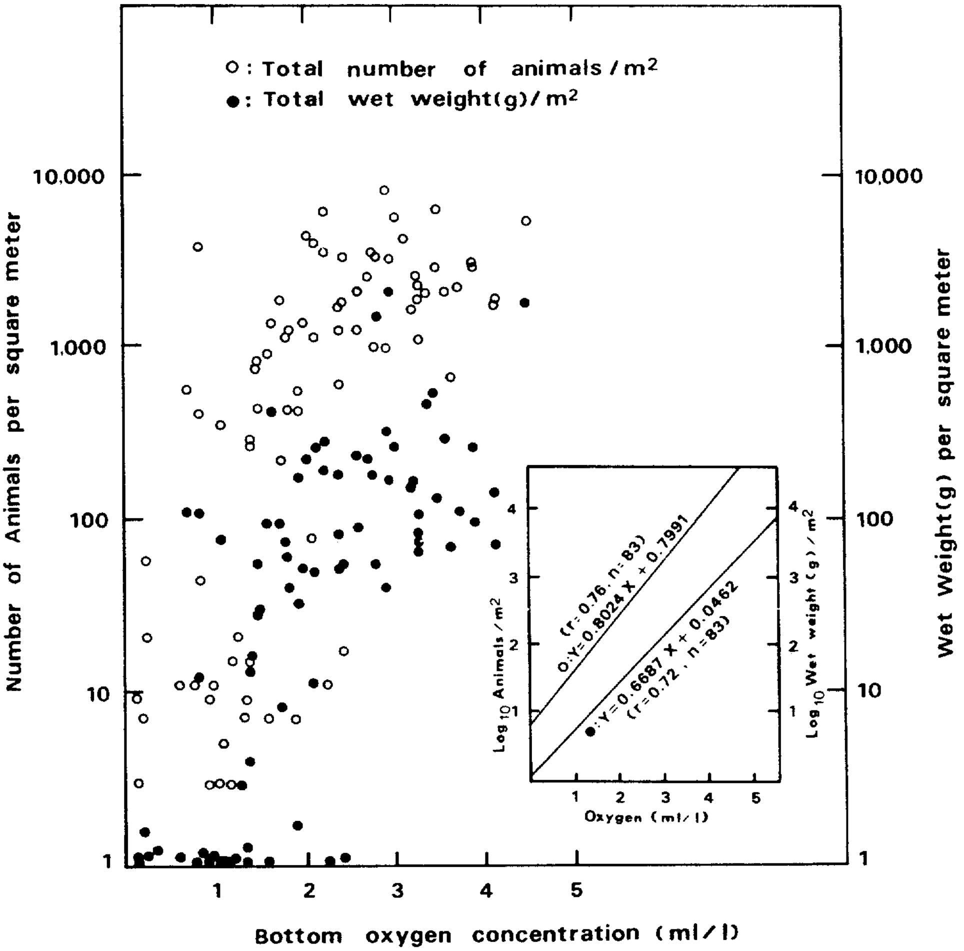

Fig. 5. Macrofaunal abundance and biomass relative to bottom oxygen concentrations. (Insert : least squares regressions of abundance and biomass measurements($\log_{10}$) versus bottom oxygen)

well as the hypoxic condition.

A considerable amount of molluscan shells were usually found in the areas where the benthic biomass was low. Therefore, the mortality of bottom fauna is presumably associated with oxygen deficiency in the bottom waters. These phenomena may be also regarded as the effects of eutrophication in this area. It may be possible that the eutrophication of this area is linked with "red-tides", which resulted in high densities of dinoflagellates and diatoms, and mortality of bottom animals can be observed due to anoxic or hypoxic conditions in the bottom water, even though certain metabolic substances of dinoflagellates can be toxic as well so that localized mass mortalities can and do occur, and can produce significant effects.

As suggested by several authors(Swanson *et al*., 1979 ; Rosenberg, 1985), the possible causes of oxygen depletion during the summer have often involved a combination of adverse meteorological and hydrographic conditions and eutrophication. It seems probable that this hypothesis may be applicable as the reason why oxygen deficiency develops in the bottom waters of this region.

From these results we suspect that oxygen seems to be a dominant ecological factor in determining the macrobenthic densities and biomass of the benthic system during the hypoxic period of September 1983. However, it is important that future benthic studies be more complete and include sampling bimonthly or at least seasonally for more than one year, with measurements of various other geochemical factors, which may regulate benthic distributions to provide a more accurate picture of the benthic community and ecological factors that control it in the Chinhae Bay System.

CONCLUSION

The present study reports the existence of bottom oxygen-deficient(hypoxic) zones in the Chinhae Bay System, Korea, measured during a preliminary survey in September 1983. This hypoxic area(with dissolved oxygen levels≤ 2 ml/l) extended over most of the bay system, covering an area of about 266km^2, out of a total of 497 $km^2$of study area(Table 1). This distribution corresponds quite well to the areas with only less than 40% oxygen saturation. The most affected zones were limited, as a whole, to more enclosed inner bay areas where the bottom water is stagnated particularly during the summer e.g. Masan and Haeng-am Bays, Kohyonsong Bay, Wonmunpo Bay, and the Chinhae Bay Proper. These reuslts may be of great importance not only to shellfish farming management but also to other fisheries of this area, since low oxygen levels result in increased susceptibility to disease and eventually death by suffocation and asphyxiation of oysters, mussels, and other bivalves cultured in this area.

It appears that low concentrations of bottom water dissolved oxygen caused sufficient stress to be manifested in low benthic

Table 1. Generalized estimation of benthic macrofaunal biomass(wet weight) and abundance(number of individuals) relative to the area affected by bottom oxygen deficiency during the preliminary survey of Septmeber 1983.

Bottom Oxygen Concentrations(ml/l)	Bottom Oxygen (%Saturation)	Affected Area(km^2)	Biomass (g/m^2)	Abundance (individuals/m^2)	Remarks*
0-1	0-20	66	0-10	0-100	Masan and Haeng-am Bay(subareas A, B) Kohyosong Bay (subarea F)
1-2	20-40	200	10-100	100-1,000	Wonmunpo Bay (subrarea E) Chinhae Bay Proper (subarea G)
2-4.5	40-90	231	100-1,000	1,000-10,000	Kadok and Chilchon Waterways (subreas C, H)

*Refer to Figure 1 for locations

biomass and abundance. However, more complete studies are required on the recolonization and stabilization of the benthic invertebrate population and the causes, mechanisms, and the behavior of oxygen-depleted water masses to minimize the impact of this event on the fisheries activities and also the role of other stressors such as toxic chemical or biological contaminations in this area. It should be emphasized that total recovery of the affected benthic community may take several years when hypoxic zones are extensive. Finally the imbalance between rates of bottom oxygen supply and utilization have the potential to change the normal coastal benthic productivity of the region to one of episodic mortality and decay as suggested by Swanson *et al.* (1979)

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