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CHARACTERISTICS OF ENVIRONMENT IN THE YATSUSHIRO SEA

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and
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ABSTRACT: The Yatsushiro Sea has serious environmental problems similar to those affecting the Ariake Sea. In this study we performed a causal analysis of environmental change in the Yatsushiro Sea by investigating environmental characteristics such as water quality and atmospheric phenomena over the past 26 years.

Numerical experiments yielded the following results: 1) there exist 5 distinct environmental domains within the Yatsushiro Sea, 2) during summer, density layers develop over the entire Yatsushiro Sea, and 3) an increase in the activity of red tides and a recent decrease in nitrification capacity indicate a decrease in oxygen content within the inner part of the Yatsushiro Sea.

A three-dimensional flow simulation produced the following results: 1) the characteristics of the tidal current in the Yatsushiro Sea are related to those of the Ariake Sea, and 2) current drift has decreased more in the inner part of the Yatsushiro sea than in the southern central part. The results of this study indicate significant ongoing change in the water environmental characteristics of the Yatsushiro Sea.

Keywords: closed bay, density layers, nitrification capacity, red tides, tidal current

1. Introduction

The Yatsushiro Sea and Ariake Sea west of Kyushu Island, Japan, contain many closed bays that have suffered environmental damage since the 1980s including a decrease in the number of marine species, red tides, a decrease in fish populations and water pollution. The environmental degradation is of serious public concern, especially the increasingly dull color of seaweed in the Ariake Sea.

The present study focuses mainly on the analysis of environmental damage in the Yatsushiro

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Sea. We performed a causal analysis of environmental damage by characterizing environmental parameters of the Yatsushiro Sea over the past 26 years. The analysis includes observation data along shallow fixed line, atmospheric phenomena and flow simulation analysis.

We conducted several analyses of observational data, described in Section 2, to determine the characteristics of environmental change within the Yatsushiro Sea. We used cluster analysis to analyze fluctuations in water quality and the characteristics of red tides. In Section 3 we investigate the characteristics of tidal current in the Yatsushiro Sea using numerical experiments based on the simulation of three-dimensional. In Section 4 we analyze precipitation and atmospheric temperature data for the Yatsushiro Sea. These data are important for understanding physical circulation in coastal areas of the Yatsushiro Sea.

2. Environmental Change in the Yatsushiro Sea

The characteristics of environmental change in the Yatsushiro Sea were investigated using fixed-line observation data collected in the Shiranui Sea over the past 26 years and data from the observation committee of the Yatsushiro Sea area.

2.1. *Cluster analysis*

Figure 1 shows 20 observation points in the Kumamoto area of the Shiranui Sea. Water temperature, salinity, dissolved oxygen (DO), chemical oxygen demand (COD), phosphoric phosphorus (PO_4-P), nitrate nitrogen (NO_3-N), nitrite nitrogen (NO_2-N), ammonia nitrogen (NH_4-N), transparency and pH were observed and analyzed on a monthly basis over the past 26 years.

Figure 1 shows 5 domains analyzed and divided into 5 groups using cluster analysis of water temperature and salinity data collected at the 20 observation points.

Changes in monthly mean water temperature of surface layers within each group are shown in figure 2. During summer, the surface water temperature was lower in the southern part (group E) than in the inner parts (groups A and B) of Yatsushiro Sea because of atmospheric influences and the small heat capacity by volume within group E. The differential of water temperature was small in group E because of the deep water in this area, the large heat capacity per volume unit, and thermal variation in the horizontal direction.

Figure 3 shows monthly variation in surface salinity within the Yatsushiro Sea. Groups A and B recorded lower salinity than group E. The differential of salinity was 4‰ in the southern areas and 8‰ in the inner areas. During the rainy season from June to August, salinity decreased due to the influx of rainwater. The inner part recorded a 23‰ decrease in salinity due to the increase in flow of rivers such as the Kuma River.

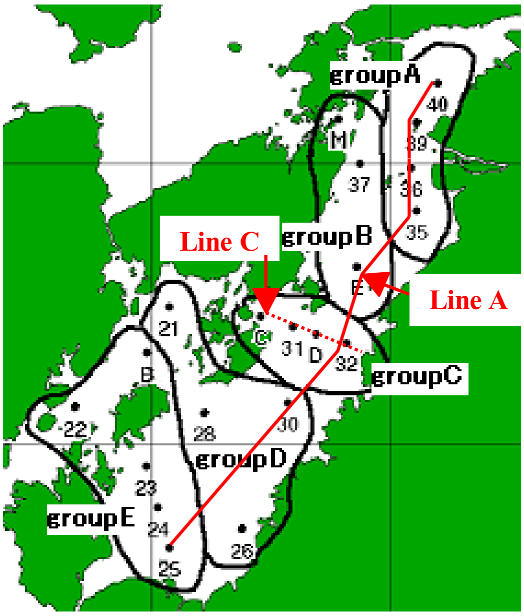


Fig. 1. Observational areas in the Yatsushiro Sea. Numbered dots represent observation stations.

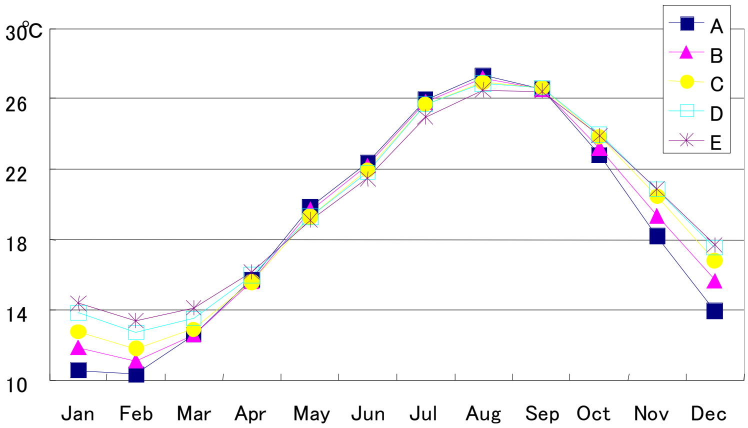


Fig. 2 Mean monthly surface layer water temperature for each group within the Yatsushiro Sea.

Fig.4 shows the mean monthly transparency recorded within each group. In the inner part (group A), such as stations 35, 36, 39 and 40, 3 m transparency was recorded; transparency was low and annual variation was minimal. The inner southern part (group B) was located at the mouth of the Kuma River. The southern part (group E) recorded higher transparency than in the central part (group C) because of the influence of seawater from the open sea that entering through the Nagashima and Kurono straits. Low summertime transparency in the central and southern parts results from seasonal rainfall and increased inflow from the Kuma River.

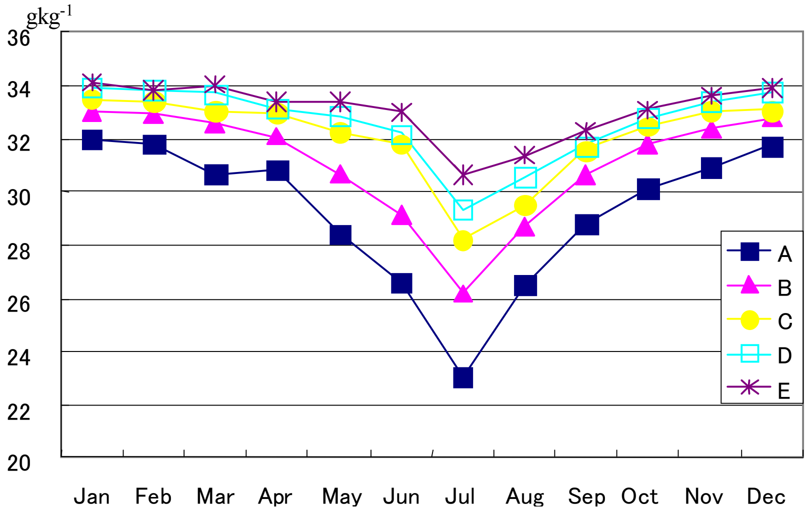


Fig. 3 Mean monthly surface layer salinity for each group within the Yatsushiro Sea

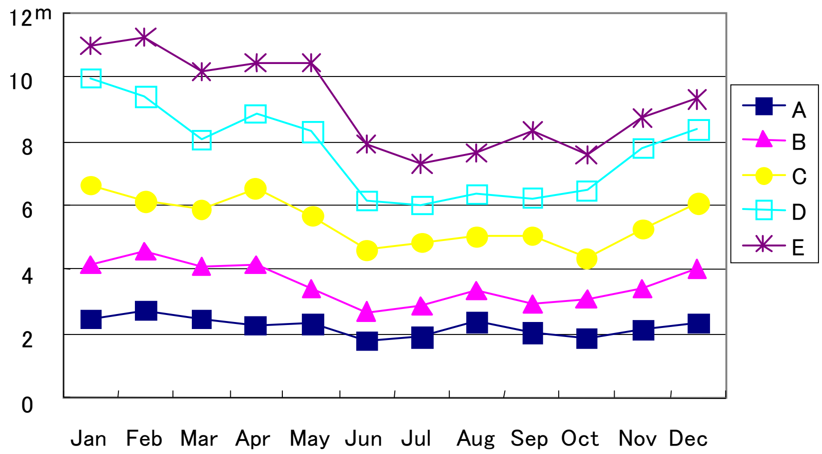


Fig. 4 Mean monthly surface layer transparency for each group within the Yatsushiro Sea

2.2 Water quality

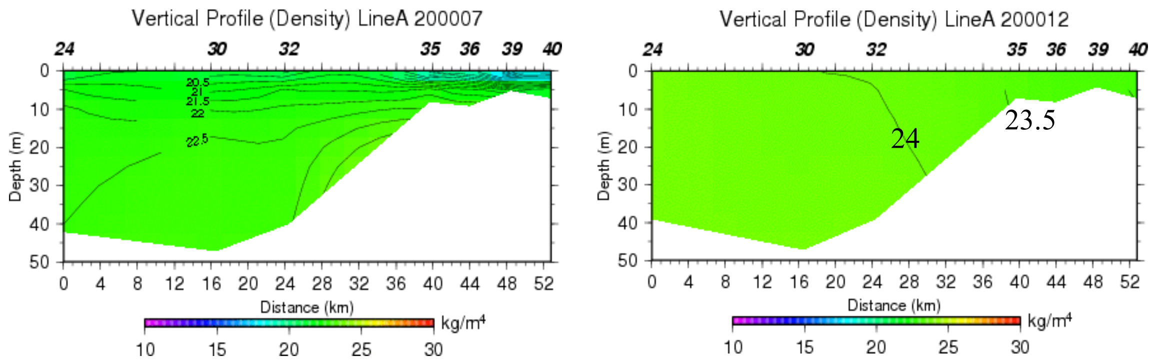
2.2.1 Vertical profile of water density

In order to perform a causal analysis of a vertical profile within the Yatsushiro Sea, we analyzed water temperature, salinity and density in a cross section through the Yatsushiro Sea. Figure 5 shows water density (σ_t), calculated from water temperature and the salinity data, in a cross section along line A (see Fig.1) for July and December 2000. Figure 6 shows equivalent data for a cross section along line C.

During the rainy season in July, low salinity develops in the surface layer of the entire Yatsushiro Sea. The inner part (group A) records 22‰ salinity at this time, 6 ‰ lower than other areas, due to the influx of fresh water from the Kuma River. July surface water temperatures are high as 26 ˚C due to the strong midsummer sunlight. As a result of figure 5(a) and 6(a) the water temperature was lower than the central and southern parts, and water density was homogeneous throughout the water column.

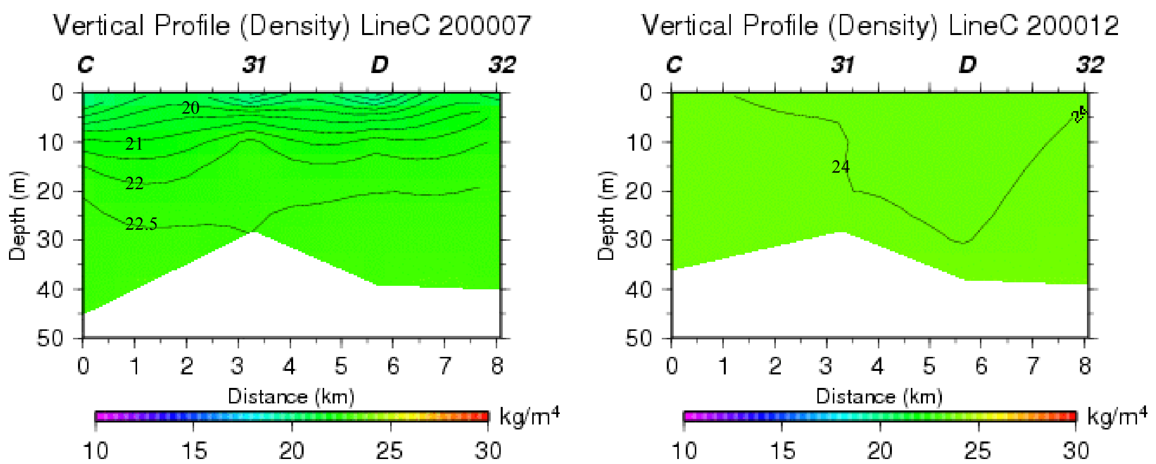
2.2.2 Changes in dissolved oxygen content

In order to perform a causal analysis of decreasing oxygen content within the Yatsushiro Sea, we examined variation in the concentration of dissolved oxygen at observation points 22, 30 and 40 for the period 1991 to 2000 (Figure 7). The annual cycle of DO can be clearly seen in Fig. 7. DO decreased to below 6 mg l^{-1} during summer, and increased during autumn to as high as 9.0 mg l^{-1}



(a) July, 2000 at Line A (b) December, 2000 at Line A

Fig. 5. Vertical Profile of Density in σ_t at Line A



(a) July, 2000 at Line C (b) December, 2000 at Line C

Fig. 6. Vertical Profile of Density in σ_t at Line C

during winter.
The concentration of dissolved oxygen is inversely proportional to temperature. Dissolved oxygen was generally low during summer because of high seasonal water temperatures, but high values were recorded during the summer of 1995 when an unusual breakout of phytoplankton occurred. Dissolved oxygen levels are lower during summer due to stratified density and high water temperatures. During the summer of 2000 the fisheries water standard was <4.3 mg l^{-1} at point 40, indicating a decrease in oxygen content within the inner part of the Yatsushiro Sea.

The frequency of outbreaks of red tides in the Yatsushiro Sea has increased in recent years, which may reflect decreasing oxygen content. Levels of dissolved oxygen are lower near the sea floor, and concerns have been raised about the environmental impacts of reduced oxygen levels.

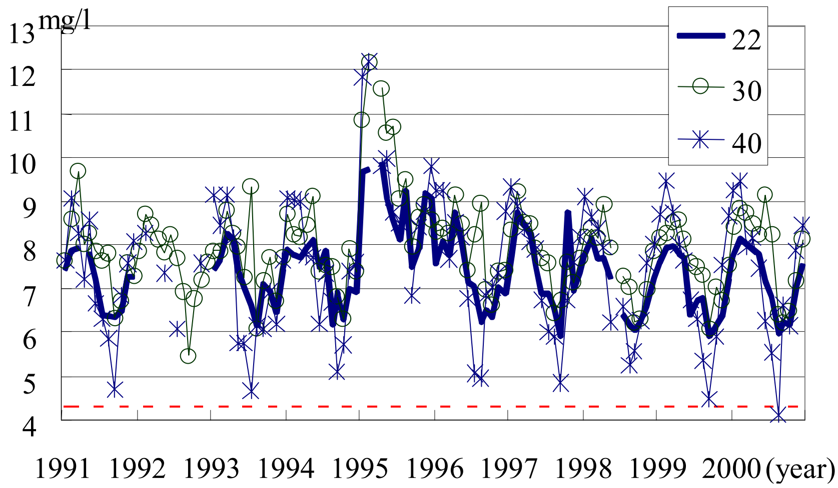


Fig.7. Variation in dissolved oxygen (1991-2000) at 5 m depth for observation points 22, 30 and 40.

2.2.3 Circulation of nitrogen

In order to perform a causal analysis of nitrogen circulation, variation in the concentration of nitrate nitrogen (NO_3-N), nitrite nitrogen (NO_2-N) and ammonia nitrogen (NH_4-N) was investigated at observation points 22, 30 and 40. Figure 8 shows variation in the mass concentration of ammonia nitrogen (NH_4-N) from 1989 to 2000. Each of the observation points recorded marked seasonal variations. The NH_4-N concentration at point 40 was generally higher than that at other points; we attribute this trend to the influence of flow from the Hikawa and Kuma Rivers into the inner (northeast) part of the Yatsushiro Sea.

Figure 9 shows variation in the ratio of nitrite nitrogen (NO_2-N) to ammonia nitrogen (NH_4-N) from 1989 to 2000. In recent times this ratio has decreased over the entire Yatsushiro Sea. At observation point 40 this decrease reflected the capacity of nitrification because the measured concentration of ammonia nitrogen (NH_4-N) was high. The recent increase in red tide occurrence and decrease in nitrification capacity has been accompanied by a decrease in dissolved oxygen content within the inner part of the Yatsushiro Sea.

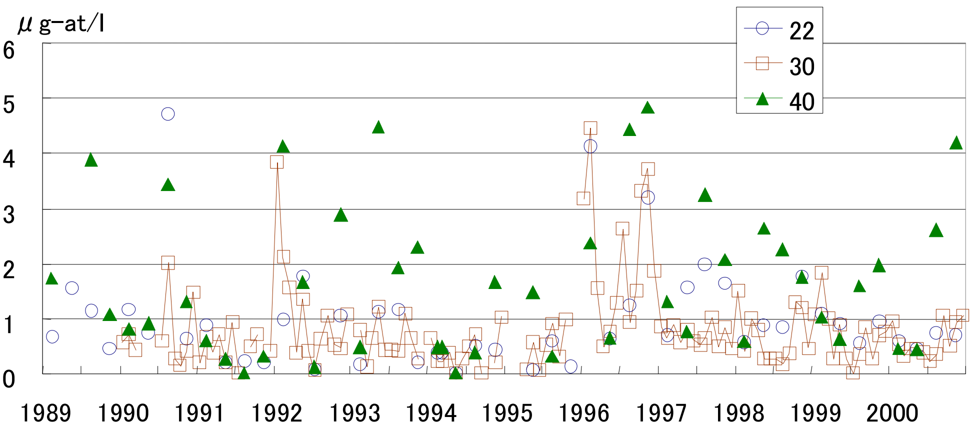


Fig. 8. Variation in the mass concentration of NH_4-N from 1989-2000

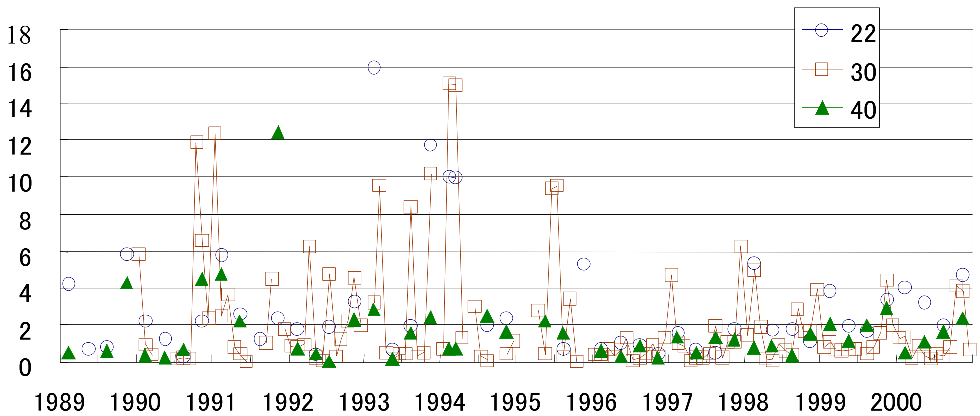


Fig. 9. Variation in the mass ratio NO_2-N/NH_4-N from 1989-2000

2.3 Characteristics of red-tides

The characteristics of red tides described below are based on data from the report of the Research and investigation committee concerning measures for the Yatsushiro Sea Area. From 1980 to the early 1990s, red tides developed in the western and southern parts of the Yatsushiro Sea, but since the early 1990s red tides have frequently appeared in the northern and inner parts of the Yatsushiro Sea. This trend has developed over the same time period as a decrease of nitrification capacity and decrease of dissolved oxygen content in the inner parts of the Yatsushiro Sea.

Figure 11 shows the seasonal distribution of red tide outbreaks. Between 1978 and 1984 80 % of red tides occurred in summer 5% during fall and about 15% during spring. During the late 1990's the proportion of red tides during summer had fallen to about 40%, about 10% occurred during fall, 10% in winter and 40% during spring.

The frequency of the outbreak of red tides was fluctuating. But they showed no fluctuation and appeared about 10 times since 1980's. Red tides typically lasted for 1-7 days during outbreaks in the early 1980's, but in recent years they commonly last for over 2 weeks.

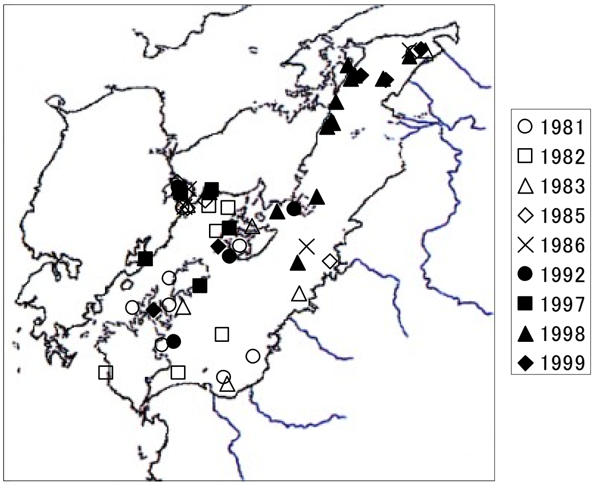


Fig.10 Distribution of red tide events, 1981-1999.

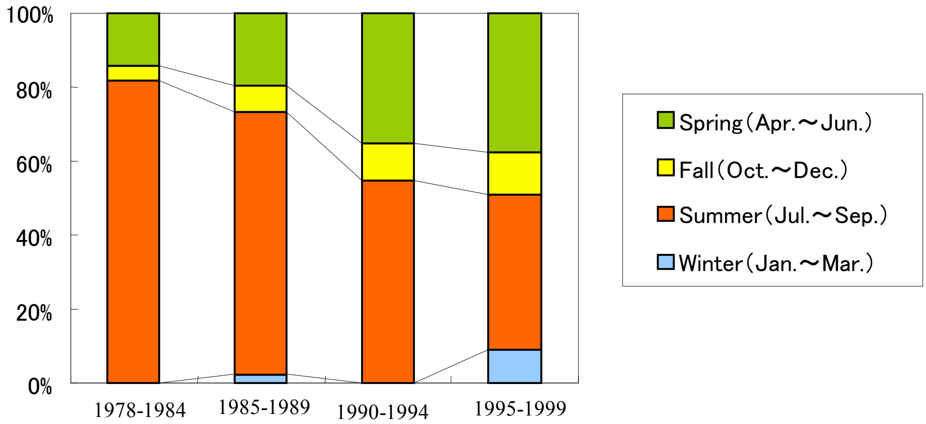
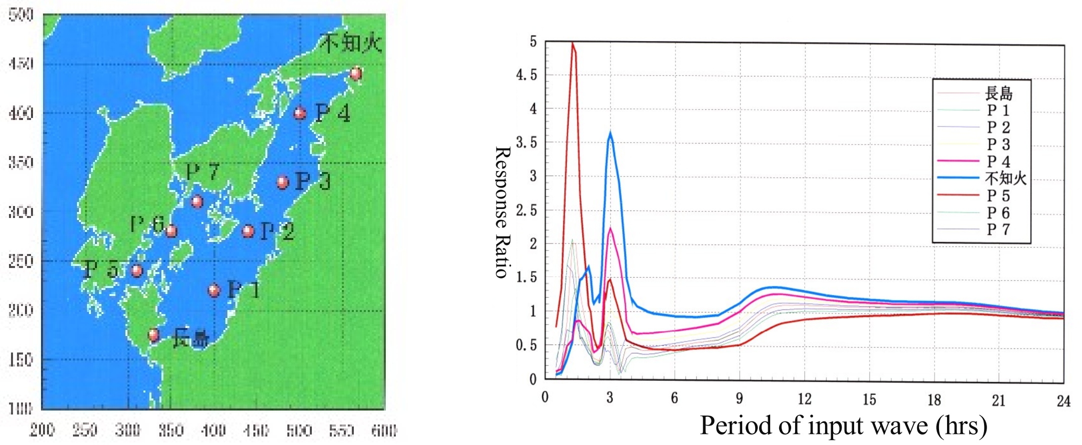


Fig.11 Seasonal distribution of red tide events, 1978-1999.

3. Characteristics of Tidal Currents in the Yatsushiro Sea

Figure 12 shows the characteristics of oscillations in the Yatsushiro Sea. The oscillation response at each observation point in the Yatsushiro Sea was calculated by 2-dimensional numerical analysis. The gulf oscillation period was about 3 hours in the Yatsushiro Sea, similar to the natural period along the length of the Yatsushiro Sea. It was observed at typhoon 9918. The oscillation response over 9 hours was influenced by the natural period of the Ariake Sea. It is necessary to consider the influence of the natural period when we investigate tidal oscillations in the Yatsushiro Sea and Ariake Sea.



(a) Locations of reference points (b) Response function

Fig.12 Gulf oscillation in the Yatsushiro Sea

Figures 13 and 14 show the results of three-dimensional numerical flow simulation (POM2k) of tidal currents within the Yatsushiro Sea. The simulation grid size was 1km, with 6 vertical layers, and the amplitude of incident waves was 1.7m such as tidal fluctuation taken at the spring tide. Figure 13 shows the mean vector of the tide current as the vertically integrated current at maximum flow of high tide and the vertically integrated current at maximum flow at low tide.

Figure 14(a) shows the tidal residual current without the influence of river inflow, while Figure 14(b) the influence of high flood discharge rates from the Hikawa River (900 m^3s^{-1}), the Kuma River (7,000m^3s^{-1}), the Sashiki River (500 m^3s^{-1}), and the Minamata River (1,100m^3s^{-1}). The modeled currents are similar to observation data (Japan Coast Guard, 1978). The simulation that accommodated inflow from the rivers predicted a residual current through the Mitsukoshi Strait and the Nagashima Strait (Figure 14b). Residual circulation of integrated flow was minor in the central eastern part to the inner part of the Yatsushiro Sea and we calculated that the tidal circulation tends to be accumulative.

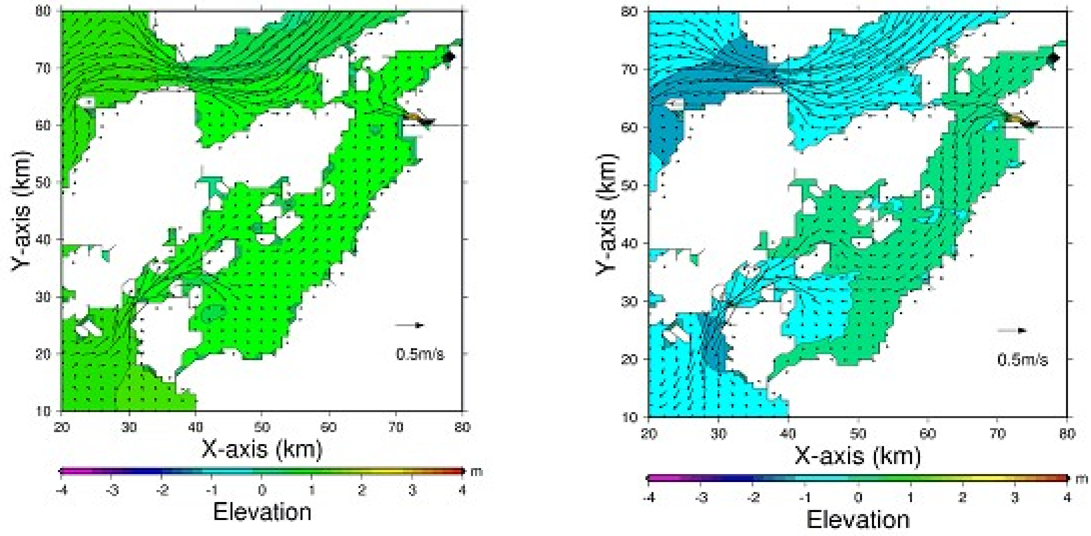


Fig.13 Comparison of the tide current at low and high tide. (a) Vertically integrated current at maximum flow of high tide. (b) Vertically integrated current at maximum flow low tide.

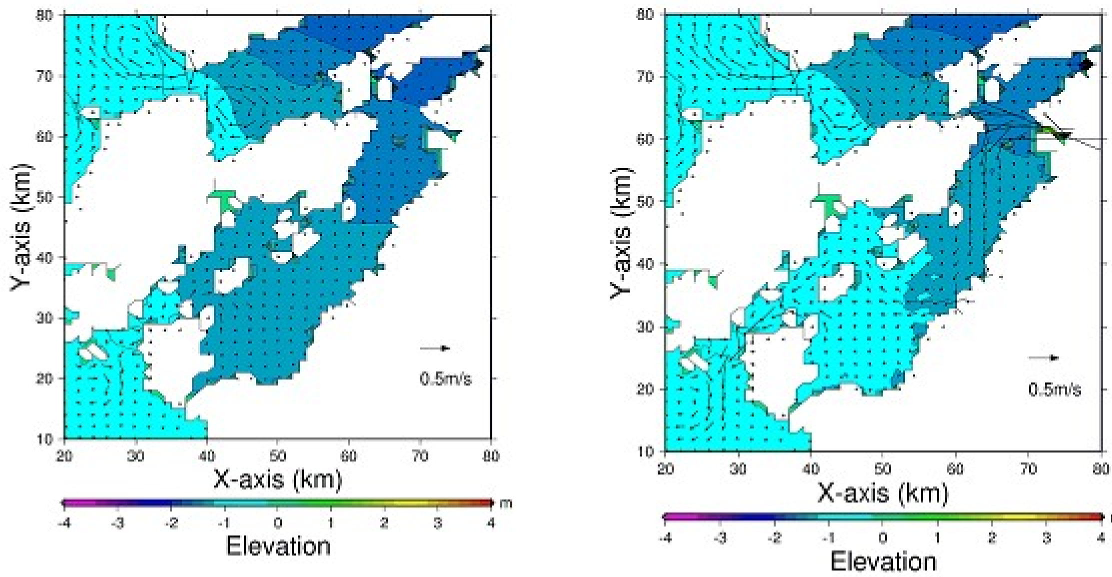


Fig.14 (a) Tidal residual current (vertically integrated value) calculated without river flow. (b) Current calculated with river flow.

4. Atmospheric temperature and precipitation in the Yatsushiro Sea area

In order to understand the material cycle in the coastal regions of the Yatsushiro Sea, it is important to document precipitation in areas such as the Kuma River basin. Figure 15 shows the mean winter air temperature in the area of the Yatsushiro Sea. The atmospheric and water temperature varies between the southeastern and inner parts of the Yatsushiro Sea. Ushibuka City, located on the southwestern part of the Yatsushiro Sea, recorded a mean winter temperature 2 to 2.5 ˚C warmer than inner parts. In recent years the mean winter air temperature in Hondo city, connected with the Ariake Sea, is higher than the temperature in Yatsushiro city, located on the eastern part of the Yatsushiro Sea.

Figure 16 shows the total precipitation during July 2002 on the basis of the grid point value for precipitation (Radar-AMeDAS reanalysis) provided by the Japan Meteorological Agency. In the area from Amakusa to the upper part of the Yatsushiro Sea the total precipitation was less than 200mm, while in mountainous areas such as the Kuma River basin precipitation was greater than 300mm. The southeastern part of Khushu Island, including the Yatsushiro Sea, has experienced many severe rainfall events, including Amakusa in 1972, Izumi in 1997, and Minamata in July 2003.

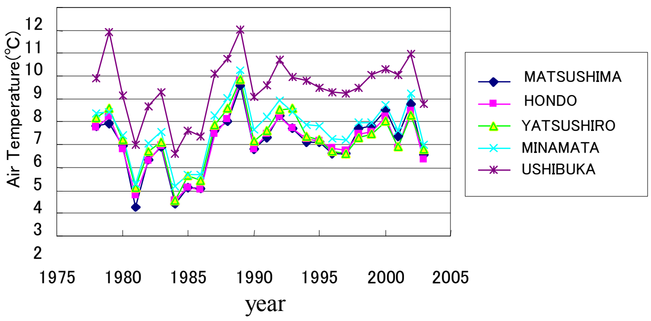


Fig.15 Mean January air temperature measured at AMeDAS observation points within the Yatsushiro Sea.

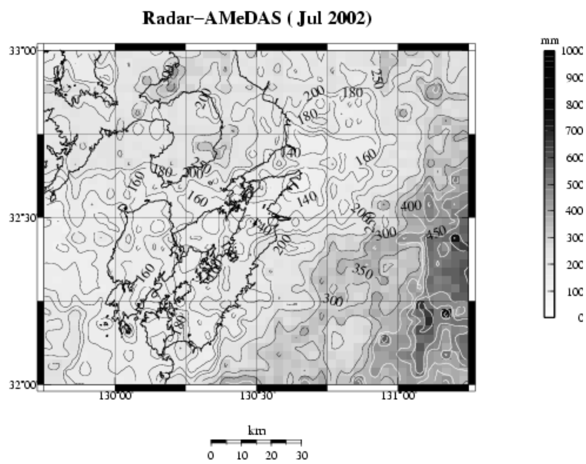


Fig.16 Precipitation in the Yatsushiro Sea during July 1992. Radar-AMeDAS reanalysis data provided by Japan Meteorological Agency.

5. Conclusions

The Yatsushiro Sea has serious environmental problems similar to those affecting the Ariake Sea. In this study we performed a causal analysis of environmental change in the Yatsushiro Sea by investigating environmental characteristics such as water quality and atmospheric phenomena over the past 26 years.

Numerical experiments yielded the following results: 1) there were 5 parts of ocean area in the Yatsushiro Sea because of the change of the water's environmental characteristics, 2) during summer, density layers develop over the entire Yatsushiro Sea, and 3) an increase in the activity of red tides and a recent decrease in nitrification capacity indicates a decrease in oxygen content within the inner part of the Yatsushiro sea.

A three-dimensional flow simulation produced the following results: 1) the characteristics of the tidal current in the Yatsushiro Sea are related to those of the Ariake Sea, and 2) current drift has decreased more in the inner part of the Yatsushiro sea than in the southern central part. The results of this study indicate significant ongoing change in the water environmental characteristics of the Yatsushiro Sea.

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