NOTE

Effect of River Discharge on the Distribution Pattern of Dissolved Constituents in the Gamō Estuary, Miyagi Prefecture*

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Abstract

This study reports a series of measurements of chlorinity, dissolved inorganic nitrogen, phosphate and oxygen in the Gamō estuary, a salt wedge estuary.

NH_4^+ and PO_4^{3-} concentrations of saline water in the salt wedge generally increased with the distance upstream, whereas dissolved oxygen concentration decreased with it. In addition, the development of anoxic condition and the accumulation of NH_4^+ and PO_4^{3-} were observed in the bottom saline water inside a series of basins. The strong local difference in the chemical properties was found in the deep water of basins separated by a shallow sill at the high river discharge. The results suggest that the increase of NH_4^+ and PO_4^{3-} concentration and the decrease of dissolved oxygen in the saline wedge are explained by detention time in the estuary and also indicate that the highly saline waters are generally trapped and isolated in the deeper parts of the basins by shallow sills. The phytoplankton bloom dominated by diatoms (*Cyclotella*) in the surface river water and the high density of ciliates (*Mesodinium*) immediately below the halocline were observed at the low river discharge.

1. Introduction

The Gamō estuary is situated about 10 km east of Sendai City (38°15'N lat., 141°1'E long.), where the Nanakita River opens into the Sendai Bay facing Pacific Ocean (Fig. 1). The Nanakita River has a length of about 45 km and a drainage area of 200 km². There is a weir about 4.2 km upstream from the mouth. The area downstream of the weir is the usual estuarine part. The Umeda River flows into the Nanakita River just upstream of this weir. The river discharge of the Nanakita River and Umeda River accounts for about 80% and 20% of that entering the estuarine part, respectively (HANAWA and SUGIMOTO, 1979). Both rivers are highly polluted with domestic sewage. As a whole, this estuary has the salinity distribution of a salt wedge type (HANAWA and SUGIMOTO, 1979). The aim of this study is to describe the distributions of some dissolved constituents which reflect the physical, chemical and

biological processes in the Gamō estuary with special reference to river discharge and bottom topography.

2. Materials and Methods

The sampling stations of water in the Gamō estuary are shown in Fig. 1. Water samples were collected with a hand-operated pump from a boat. The first subsample collected from each depth was used for determination of the dissolved oxygen concentration following the method of Winkler as modified by STRICKLAND and PARSONS (1972). A second subsample collected in acid-washed polyethylene bottles was filtered (Whatman GF/C glass-fiber filter) and frozen. Frozen samples were thawed and analyzed for ammonium, nitrate, nitrite and phosphate following methods outlined by STRICKLAND and PARSONS (1972). A third subsample was drawn for chlorinity determination. Chlorinity was determined by silver nitrate titration. A fourth subsample was preserved with 5% formalin for examination of plankton.

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Fig. 1. Station position in the Gamō estuary.

3. Results and Discussions

1. Longitudinal distributions of dissolved constituents in moderate river discharge

The longitudinal distributions of dissolved constituents on 6 July 1976 (river discharge, $3 \text{ m}^3/\text{sec}$) are shown in Fig. 2. River discharges were estimated from Q-H curve according to HANAWA and SUGIMOTO (1979). Water samples of st. 1, 3, 5, 6 and 7 were taken at flood tide, and water samples of only st. 4 were taken at ebb tide. Thus, it seems that Fig. 2 indicated the rough distribution of dissolved constituents at a flood tide. There was an intrusion of a saline wedge along the bottom, bounded by

a sharp halocline of up to 15‰ (chlorinity) in less than 0.5 m, from the fresh river water on the surface (Fig. 2-(a)). The salt wedge penetrated up to the weir, 4.2 km upstream from the mouth. The chlorinity of saline water entering the estuary along the bottom was not different from that of sea water. The chlorinity in the salt wedge decreased a little from the mouth to the wedge tip, and the salt water was slightly entrained by the surface freshwater.

The concentrations of NO_3^- were considerably higher in the surface river water than in the saline water of the salt wedge. The concentration markedly decreased with the increase of chlorinity in the halocline

Fig. 2-(a). Bathymetric profile of the Gamō estuary and longitudinal distribution of chlorinity (‰) at the moderate river discharge on 6 July 1976.

Fig. 2-(b). Longitudinal distribution of $\text{NO}_3\text{-N}$ ($\mu\text{g-at/l}$) at the moderate river discharge on 6 July 1976.

Fig. 2-(c). Longitudinal distribution of $\text{NH}_4^+\text{-N}$ ($\mu\text{g-at/l}$) at the moderate river discharge on 6 July 1976.

Fig. 2-(d). Longitudinal distribution of $\text{PO}_4^{3-}\text{-P}$ ($\mu\text{g-at/l}$) at the moderate river discharge on 6 July 1976.

Fig. 2-(e). Longitudinal distribution of dissolved oxygen (%) at the moderate river discharge on 6 July 1976. .

(Fig. 2-(b)). The concentration of NO_3^- in sea water was much lower than in the river water (Table 1). These results suggest that the concentration of NO_3^- is determined by the dilution of the river water by the sea water.

The concentrations of NH_4^+ and PO_4^{3-} in the surface river water were fairly uniform along the transect, while those in the saline water of salt wedge markedly increased to the wedge tip and with the depth especially inside the deep basins (Fig. 2-(c) and (d)). However, the chlorinity varied little from the wedge tip to the estuary mouth and with depth within the salt wedge (Fig. 2-(a)). Unlike NH_4^+ and PO_4^{3-} , the dissolved oxygen in the salt wedge markedly decreased to the wedge tip and with the depth. The concentrations of NH_4^+ and PO_4^{3-} in sea water entering the estuary were lower and the concentrations of dissolved oxygen in sea water were higher than those of the saline water of the wedge tip and the deep

water inside the basins. It is known that in the deeper parts of several estuaries and fjords, shallow sills have restricted the circulation of water and the resulting salinity-dominated stability profile leaves the deep saline water stagnant and allows the development of anoxic condition and the accumulation of NH_4^+ and PO_4^{3-} (DAYER and RAMAMOORTHY, 1968; RICHARDS *et al.*, 1971; GAIN and PILSON, 1972; WELCH *et al.*, 1972). In addition, the detention time of saline water within the wedge increases from the estuarine mouth to the wedge tip. Therefore, our results suggest that the concentrations of NH_4^+ and PO_4^{3-} in saline water increase and that of dissolved oxygen decreases with the increase of detention time in the estuary as the result of the decomposition of organic matter in the water and sediment. As for the distribution of dissolved oxygen, a similar result was obtained by FRANKENBERG (1976) in the

Table 1. The chlorinity and the concentrations of dissolved oxygen, ammonia, nitrate, nitrite, and phosphate in the sea water which penetrated upstream through the mouth at a flood tide (1000 hours) and in the river water (5 km upstream from the mouth) at 1000 hours on 6 July 1976.

	chlorinity (‰)	DO(%)	$\text{NH}_4^+\text{-N}^*$	$\text{NO}_3^-\text{-N}^*$	$\text{NO}_2^-\text{-N}^*$	$\text{PO}_4^{3-}\text{-P}^*$
Sea water	17.6	96	0.1	1.0	0.1	0.3
Umeda river	0.2	100	79	56	6.2	5.3
Nanakita river	0.2	93	25	31	1.8	2.4

* $\mu\text{g-at/l}$

Duplin River, Georgia, a lagoon-type tidal river.

Figure 3 shows the vertical distributions of dissolved constituents of st. 5 at flood and ebb tide. There was little difference in the vertical distributions of dissolved constituents between flood tide and ebb tide. HANAWA and SUGIMOTO (1979) reported that the salinity variations induced by the tide throughout the salt wedge are negligible in the Gamō estuary, and the tide

Fig. 3. Vertical distributions of dissolved constituents at st. 5 (2.7 km upstream from the mouth) on 6 July 1976.
—flood tide (1000 hours)
----ebb tide (1400 hours).

influences only the thickness and the salinity distribution near the mouth. These results suggest that the effect of the tide on the distribution of dissolved constituents was almost negligible in the estuary except near the mouth area. The behaviour of dissolved matter near the mouth with tidal cycle awaits further study.

2. The longitudinal distributions of dissolved constituents in the high river discharge

Figure 4 shows the distribution of dissolved constituents at flood tide on 19 August 1976 (river discharge, $15 \text{ m}^3/\text{sec}$). The saline water penetrated along the

bottom up to 1 km from the mouth and the halocline was present at the depth below 2 m. The chlorinity of water within the salt wedge increased with the depth. The chlorinity of bottom water in the basins (8-11‰) was lower than that of sea water, indicating that the sea water within the salt wedge was diluted considerably by river water. HANAWA and SUGIMOTO (1979) reported that in the high river discharge, the sea water just outside of the mouth, which had already been diluted considerably with river water, flowed into the Gamō estuary at flood tide. They estimated that the limit of the river discharge which is able to prevent the intrusion of the salt wedge into the estuary is about $30 \text{ m}^3/\text{sec}$. The strong differences in the chemical properties were found in the deep layer between two basins, st. 2 and st. 3, being separated by a shallow sill. At st. 2, a basin nearer to the mouth, the concentrations of NO_3^- , NH_4^+ and PO_4^{3-} of deep saline water were lower than those of fresh river water, suggesting the recent infiltration of seawater diluted with river water. However, in the deep water of st. 3, the concentration of NH_4^+ was higher and that of dissolved oxygen was lower than those of the surface river water. This result suggests that the deep saline water of st. 3 was trapped and isolated by a shallow sill for a relatively long period. Thus, NH_4^+ was accumulated and dissolved oxygen was consumed by decomposition of organic matter in the water and sediment. The NO_3^- concentrations in saline waters at both st. 2 and st. 3 decreased with increasing chlorinity. The linearity in the NO_3^- chlorinity relationship (Fig. 5) indicates the concentration of NO_3^- might be determined by the dilution of river water with seawater.

3. Vertical distributions of dissolved constituents after the long-term low river discharge

Figures 6 and 7 show the vertical distributions of dissolved constituents and plankton at st. 5 on 21 August 1975 (river discharge, less than $0.1 \text{ m}^3/\text{sec}$). There was little rainfall in August 1975. The

Fig. 4. Longitudinal distribution of (a) chlorinity, (b) NO_3^- -N, (c) NH_4^+ -N, (d) PO_4^{3-} -P and (e) dissolved oxygen at the high river discharge on 19 August 1976.

vertical distribution of chlorinity shows that the strong halocline was present at the depth from 0.5 m to 0.75 m at low water (0930 hours). This halocline was pushed upwards until it reached the surface at high water (1600 hours), indicating that the development of a saline wedge pushed

the river water upstream and impounded it in the upper estuary. The chlorinity of the surface river water was about 6‰. This indicates the river water entrained the saline water of the wedge and the distribution of chlorinity was similar to the near-partially mixed estuary.

Fig. 5. Relationship between nitrate concentration and chlorinity at the high river discharge on 19 August 1976. st. 2 ○, st. 3 ●, seawater ⊙.

The most striking characteristics of the vertical distribution of dissolved constituents were the very high concentration of dissolved oxygen in the surface brackish river water and its very low concentration of NH_4^+ , NO_3^- and PO_4^{3-} . In the brackish surface water, the phytoplankton bloom dominated by diatoms, *Cyclotella atomus* and *Cyclotella meneghiniana*, was also

Fig. 6. Vertical distributions of dissolved constituents at st. 5 on 21 August 1975 after the long duration of the low river discharge. — low water (0930 hours), - - - flood tide (1300 hours), ···· high water (1600 hours).

observed. This indicates that the very high concentration of dissolved oxygen and the very low concentrations of NH_4^+ , PO_4^{3-} and NO_3^- in the surface river water were caused by the production of dissolved oxygen and consumption of NH_4^+ , PO_4^{3-} and NO_3^- by the phytoplankton. The low river discharge in summer may maximize the detention

Fig. 7. The vertical distributions of plankton at st. 5 in the low river discharge on 21 August 1975. —●— flood tide (1300 hours), --○-- high water (1600 hours).

time of the river water in the river and estuary, and allow time for a number of cell divisions sufficient to produce a bloom. The saline layer below the halocline was characterized by the rapid vertical decrease in dissolved oxygen and the vertical increase in PO_4^{3-} and NH_4 with depth. As for phytoplankton, *Skeletonema* sp. occurred below the halocline. It is noticeable that a large number of *Mesodinium* sp. was observed immediately below the halocline. Our survey also revealed that 1.6×10^5 per ml of *Cyclotella* spp. occurred in the fresh river water at 6 km upstream from the mouth and 2.8×10^4 per ml of *Skeletonema* sp. occurred in the sea water which penetrated the mouth. This suggests *Cyclotella* spp. and *Skeletonema* sp. were derived from river and sea water, respectively. *Mesodinium* sp. was not observed in either sea or river water. The low river discharge tended to maximize the detention time of saline water within the wedge as well as the distance the salt wedge penetrated the estuary. Consequently, *Mesodinium* sp. was allowed to grow and accumulate at the upper part of the salt wedge in the estuary.

摘 要

仙台湾に注ぐ七北田川の下流に位置する蒲生河口域において、水体中の溶存物質（塩素量、溶存酸素、 NO_3^- 、 NH_4^+ 、 PO_4^{3-} ）の濃度分布と河川流量および河川地形との関係を調べた。

1. 蒲生河口域は、河川水と海水とがほとんど混じらず上下二層をなす塩水楔型（二層流型）の河口域である。

2. 下層塩水部の NH_4^+ 、 PO_4^{3-} 濃度は上流にいくほど高くなり、溶存酸素は上流にいくほど低下する。また、河底地形の凹部には、高塩分濃度の塩水が滞留し、塩水中の NH_4^+ 、 PO_4^{3-} 濃度は、底部へいくにつれて増加し、溶存酸素は減少する。

3. 1975 年 8 月には、低河川流量の日が続き、河川水部では、植物プランクトン (*Cyclotella*) が大量に増殖し、 NH_4^+ 、 PO_4^{3-} 、 NO_3^- 濃度は極めて低下し、溶存酸素濃度は過飽和となった。また、塩水躍層直下には繊毛虫 (*Mesodinium*) が出現した。

4. 河川流量が増加すると、河口域部に滞留する塩水は海へ吐出され、塩水楔の長さが短くなるとともに、塩水楔内の水塊の塩分濃度が低下する。

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