17th International Symposium on Ice
Saint Petersburg, Russia, 21 - 25 June 2004
International Association of Hydraulic Engineering and Research

LONG-TERM MODELING OF WATER QUALITY FOR STAGNATED WATER AREA IN SNOWY COLD REGIONS

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ABSTRACT

The largest one of oxbow-shaped river formed by the cut-off work of the Ishikari river is the Barato river where the multi-function consisting of flood regulation, fishing, as well as conservation of riparian environment are expected, while the water pollution like eutrophication has been the problem due to flow stagnancy and inflow of pollutant load from the urbanized area. In the Barato river locating in the snowy cold region, ice cover condition as well as much inflow due to snowmelt play an important role on water quality. A long-term model of water quality is needed to verify the effectiveness of environmental protection measures and changes in freezing and snowmelt caused by global warming. We propose a long-term water quality model that takes into account ice cover and inflow of pollutant loads in the snowmelt season. It was verified that the model can calculate the growth and decay of phytoplankton based on water budget, heat flux and pollutant load.

INTRODUCTION

This study focuses on the Barato River (Figure 1), which was formed when a meander of the Ishikari River was cut off in the early Showa Era (1926 – 1988). The Barato River is located in the north of Sapporo, a city of almost 2 million people. The water environment of the river offers a place of recreation for city residents. It is also rich in fish, such as pond smelt (Photo 1). However, the Barato River is largely a closed water body. Inflow of pollutant substances from the urban area has caused eutrophication there. Since the Barato River is located at a high latitude, it freezes in winter, and snowmelt water brings in large amounts of pollutant loads. When evaluating the water quality of the Barato River, the effects of freezing and snowmelt cannot be neglected. The water environment has been improved by sediment dredging and improvements in the sewerage system. However, the problem of eutrophication has not been solved. This paper proposes a water quality model for the Barato River toward examining how seasonal conditions unique to snowy cold regions affect water quality.

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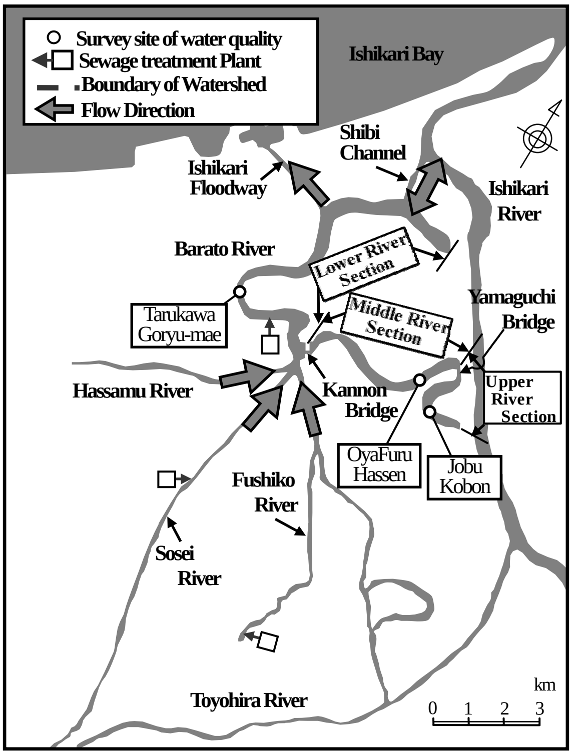

Fig. 1. Barato River and water flow direction

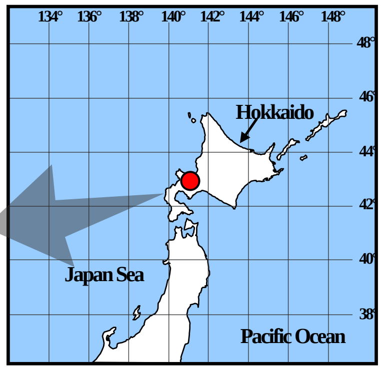

Photo 1. Pond smelt fishing on the ice- covered Barato River

1) Water budget and nutrient load budget were estimated to explore features of the Barato River, such as stagnancy and load origin.
2) The water quality of the Barato River was surveyed to determine the water quality characteristics of a stagnant water body in a snowy cold region
3) The estimated water and load budgets were used to simulate water temperature and quality (Di Toro *et al*., 1971). The simulation included the effects of phytoplankton species of each season. An ecological model of diatoms, green algae, and cyanobacteria was applied.
4) Based on the water quality model constructed, temperature and freezing conditions were varied to analyze the effects on water quality.

WATER AND LOAD BUDGETS IN THE BARATO RIVER

Topography of the Barato River

The Barato River is divided in three sections: upper, middle, and lower (Figure 1). The sections are interconnected by narrow waterways. We take into account water flows from five sources: 1) inflow from rivers (the Sosei, Fushiko, and Hassamu rivers), 2) backflow from the Shibi Channel, 3) discharge from the Barato Sewage Treatment Plant, 4) stormwater from areas without a sewerage treatment facility, and 5) groundwater. When the water level is normal, water is discharged to the Ishikari River via the Shibi Channel. During severe flooding, the Shibi Channel is closed, and water is discharged via the Ishikari Floodway. The Barato River is near the backwater section of the Ishikari River. The water level and water flow of the Barato River periodically change with the tidal level of Ishikari Bay. The flow at Kannon Bridge and Yamaguchi Bridge (Figure 1), which are built over waterways connecting the sections, strongly relates to the diurnal water level changes in the Barato River. The tidal level change is a dominant factor determining the exchange of water between the river sections.

Water budget

Figure 2 shows the volume of water flowing into the Barato River by source. The largest amount of inflow is backflow from the Ishikari River via the Shibi Channel. The lower section receives 90% of water inflow, *i.e.*, water flowing from the Shibi Channel, the Sosei, Fushiko, and Hassamu Rivers, and the Barato Sewage Treatment Plant (Figure 1). The water exchange rate of the lower river section is higher than those of the middle and upper sections. The level of stagnancy is higher in these two river sections because no large rivers flow into them (Hamahara *et al.*, 2004). A distinctive feature of the Barato River is the existence of sections with very different degrees of stagnancy. This greatly affects the water quality in the river.

Supply of nutrient loads

This section describes the characteristics of nutrient loads. Primary production in the Barato River appears to be controlled by phosphorus. Figure 3 shows daily mean phosphorus loads to the Barato River. Based on the measurement using the sediment trap, we estimated the amount of substances exchanged between the water and the sediment by sedimentation and resuspension. Chlorophyll-a measurements were used as indexes to differentiate between the resuspended sediment and autochthonous matter, in order to determine the volume of the former (Fukushima *et al.*, 1984). n each of the three river sections, suspended load from sediment accounts for most of the load (Figure 3). As in the case of water budget, the percentage of suspended load from sediment in the upper and middle river sections exceeds that in the lower river section, because no large rivers flow into the upper and middle river sections.

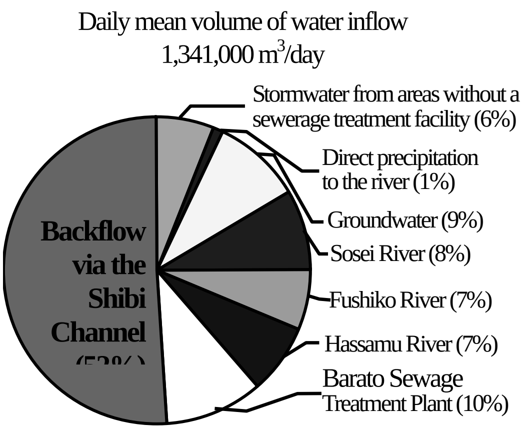

Fig. 2. Volume of water inflow by source (1997 – 2001)

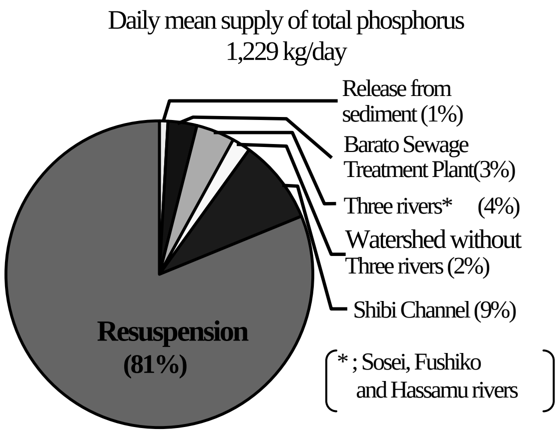

Fig. 3. Supply of total phosphorus (T-P) loads by source (April - November, 1997 – 2001)

WATER QUALITY IN CHARACTERISTICS OF BARATO RIVER

The averages of the observed phosphorus concentrations for each month of the 6 years from 1997 to 2002 are shown in Figure 4, where I-P and O-P denote inorganic and organic phosphorus concentrations, respectively. The figures indicate that the phosphorus concentrations are

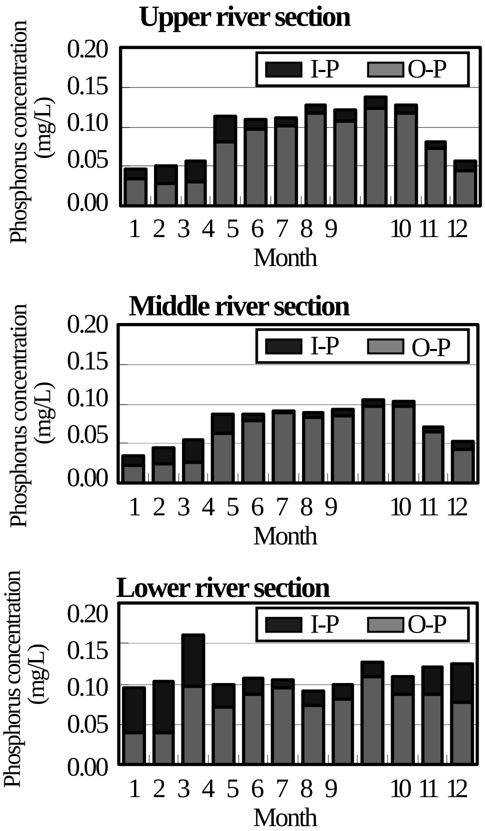

Fig. 4. Phosphorus concentration of each month (average values of 1997 – 2002)

low from January to March in the upper and middle river sections. Although phosphorus loads in these sections are high due to resuspension, they are low in winter because freezing reduces wind and wave action, which in turn reduces resuspension. This trend cannot be seen in the lower river section. The phosphorus loads are high there in March. The lower river section has more sources of water inflow, so it receives some supply of phosphorus even in winter. The percentages of I-P in T-P during summer are low compared with those during the freezing season because plankton consumes I-P in summer. This phenomenon occurs to a greater degree in middle and upper sections than in the lower section, where the level of I-P is optimized through consumption by plankton.

MODELING FOR EUTROPHICATION

The water and substance cycles of the Barato River discussed above were incorporated in the simulations that we performed. The simulations included flow simulation, water temperature simulation using the heat balance analysis results, and water quality simulation using an ecological model. The duration was 2001/1/1, to 2002/12/31. For calculation, the river was assumed to be completely ice-covered in January, February, and March of these two years.

Flow simulation

The flow of the Barato River needs to be simulated for estimation of water temperature and quality. Discharge was calculated by a one-dimensional unsteady flow model. Here, we apply the finite difference method to the momentum equation (1) and the continuity equation (2), which are the basic equations of the one-dimensional unsteady flow model. The leapfrog scheme was applied for numerical calculation. The 20-km-long course of the Barato River was divided into 25 sections (Figure 5). The flows from the three rivers, the Ishikari Floodway, and the Shibi Channel are provided as lateral flow.

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q \quad , \tag{1}$$

$$\frac{1}{gA}\frac{\partial Q}{\partial t} - \frac{Q}{gA^2}\frac{\partial A}{\partial t} + \frac{Q}{gA^2}\frac{\partial Q}{\partial x} - \frac{Q^2}{gA^3}\frac{\partial A}{\partial x} + \frac{Q}{gA^2}q - i + \frac{\partial h}{\partial x} + \frac{n^2|Q|Q}{A^2R^{4/3}} = 0 \; , \tag{2}$$

where Q is discharge (m^3/s), A is cross-sectional area (m^2), h is water depth (m), R is hydraulic radius (m), n is Manning's roughness coefficient, q is lateral inflow (m^3/s), i is riverbed gradient,

t is time (sec.) and x is distance (m). Calculations were made to obtain data for every 2 seconds. Then, the calculated results were averaged for each hour. Since forward flow alternates with backward flow in the Barato River, numerical calculation could be diverged by flow direction change. To mitigate the effects of flow direction change, the water level change and discharge values were reset at hourly interval to the default, *i.e.*, the water level was reset to the constant, *e.g.*, resulting from the observation and the discharge was reset to 0. During that hour, boundary conditions, such as inflow and outflow of the river sections, were assumed to be constant, to simplify the calculation.

Water temperature and quality simulation

The ecological model, which we will describe later, performs simulation for each of the three phytoplankton species. Water temperature is an important factor for the simulation. The hydrological characteristics of the Barato River are complicated by various factors, including the tidal level change and the bottleneck for flow. Therefore, water temperature needs to be estimated at the interval less than an hour. Heat flux is related to exchange of water with other water bodies and interactions at the air-water interface. The heat flux at the water surface, ϕ can be calculated from Equation (4), and the obtained results were substituted into Equation (3) to estimate the water temperature of each of the three river sections.

$$\frac{d(TV)}{dt} = T_{in}Q_{in} - TQ_{out} + \phi \quad , \tag{3}$$

$$\phi = \frac{A_w}{\rho C_w}\{(1-\alpha)S\downarrow + L\downarrow - \varepsilon\sigma T^4 - H - lE\} \quad , \tag{4}$$

where T is water temperature (K), Q is discharge (m^3/s), V is volume (m^3), ρ is water density (1000 kg/m^3), C_w is specific heat of water (4,180 J/deg/kg), α is water surface albedo, $S\downarrow$ is solar radiation (W/m^2), $L\downarrow$ is downward long-wave radiation (W/m^2), H is sensible heat flux (W/m^2), lE is latent heat flux (W/m^2), A_w is water surface area (m^2), ε is emissivity and σ is Stefan-Boltzmann constant (5.67 x 10^{-8} W/m^2/K^4). We assigned to Q and V the previously calculated discharge values. During the freezing period, the water temperature is fairly stable. The average value of January through March was assigned as the water temperature.

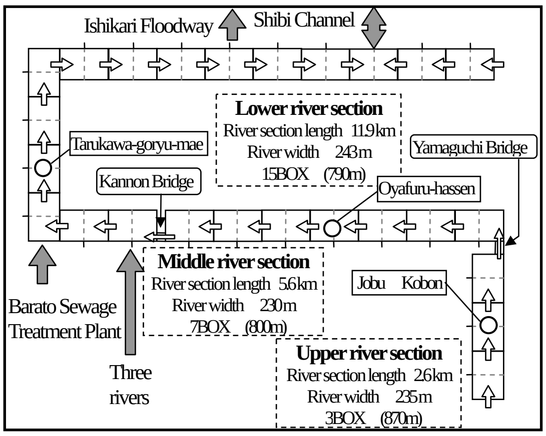

Fig. 5. Schematic of the survey area

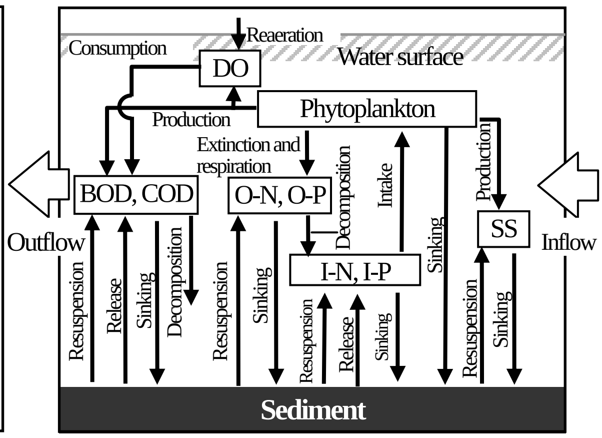

Fig. 6. Schematic of the water quality model model

Since the Barato River is in a snowy cold region, the phytoplankton species propagating after the snowmelt period in spring differ from those propagating during summer. An ecological model was constructed to reproduce chlorophyll-a concentration of diatom, green algae, and cyanobacteria. DO, SS, organic matter (BOD and COD), and nutrient (I-N, O-N, I-P, and O-P) were incorporated into the calculation because they are considered responsible for eutrophication. The water quality model is shown in Figure 6. The volumes of the substances exchanged between the river water and sediment due to resuspension and sedimentation were estimated in the same manner as for load. Resuspension was assumed not to occur during the freezing season.

$$\frac{d(CV)}{dt} = C_{in}Q_{in} - CQ_{out} + V\psi \tag{5}$$

where C is water quality component concentration (mg/L), Q is discharge (m^3/s), V is volume (m^3) and ψ is growth/decline term (mg/L/s). Equation (6) shows the growth/decline term for chlorophyll-a.

$$\psi(C_{PP}) = \sum_{i=1,3}\{(G_{Pi} - D_{Pi})P_i - v_{Pi}P_i\} \tag{6}$$

where C_{PP} is chlorophyll-a concentration (μg/L), i is phytoplankton species (1: diatoms, 2: green algae, 3:cyanobacteria), G_{Pi} is growth rate of phytoplankton (1/s), D_{Pi} is death rate of phytoplankton (1/s) and v_{Pi} is sinking rate of phytoplankton (1/s). During the freezing period, we assumed $G_{Pi} = 0$ (sunlight required for survival of phytoplankton is unavailable). The parameters of the model were assigned based on the existing survey and examinations such as Algal Growth Potential test.

Water temperature and quality reproduced by the model

Figures 7 and 8 respectively show estimates of water temperature and chlorophyll-a concentration in the middle river section. The water temperature estimates are fairly accurate (Figure 7). In this section, the water quality changed according to the seasonal changes in plankton population: 1) The population increased due to inflow of loads by snowmelt water, 2) it decreased from phosphorus shortage, and 3) it increased again in summer. Estimates of chlorophyll-a concen-

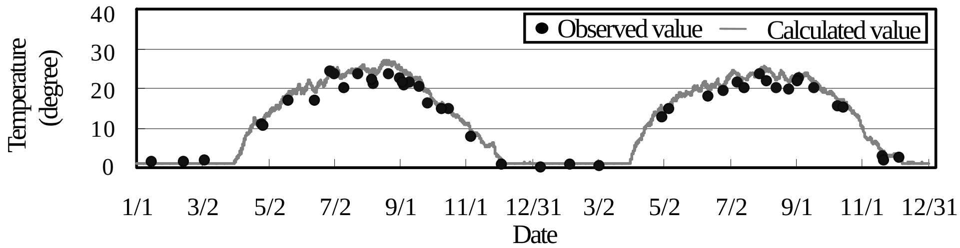

Fig. 7. Water temperature estimates for the middle river section (2001-2002)

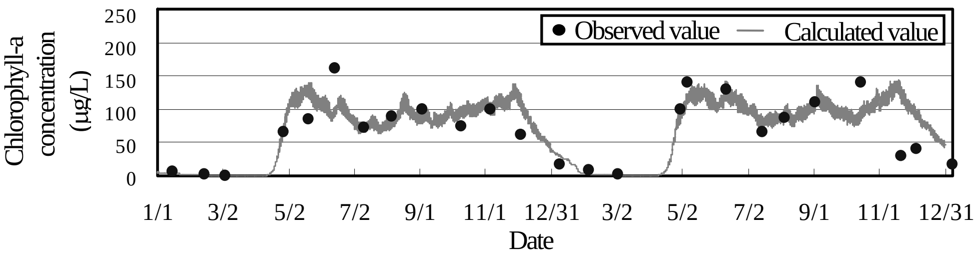

Fig. 8. Chlorophyll-a concentration estimates for the middle river section (2001 – 2002) ((2001 – 2002)

tration show that it increased in May due to snowmelt flood, decreases in June, and then increased again after summer (Figure 8). These estimates agree well with the observed values presented in the same figure. This model can accurately simulate the characteristics of water quality changes in snowy cold regions.

EFFECTS OF CHANGES IN AIR TEMPERRATURE AND FREEZING DURATION ON WATER QUALITY

As mentioned above, air temperature and freezing duration affect the water quality in the Barato River. The relationship between the air temperature and the water quality in the river was studied according to the past data. The chlorophyll-a concentration was found to decrease as the temperature increases in the non-freezing period (April - November) (Figure 9). Figure 10 shows the cumulative temperature (the sum of the daily average temperatures above freezing) during the snowmelt period (March - April) and the chlorophyll-a concentration after snowmelt (May - June). In the figure, the concentration increases with an increase in the temperature. We assumed that Figure 9 demonstrates the effects of water temperature changes caused by the air temperature increase, while Figure 10 demonstrates the effects of the shortening of the freezing period. Based on these assumptions, we conducted sensitivity analysis using the model. Tables 1 and 2 show the freezing duration and temperature settings, respectively.

Calculations were made for different air temperatures. The temperature of the inflow water was assumed to be constant because the main inflow, *i.e.*, groundwater and sewer water are affected little by air temperature. Figure 11 shows chlorophyll-a concentrations resulting from

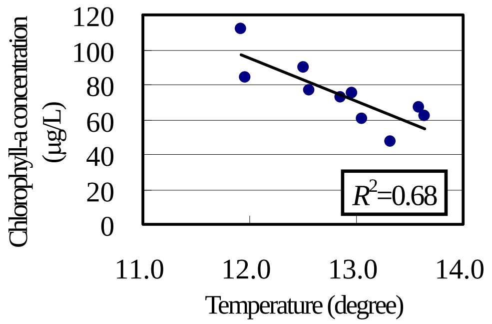

Fig. 9. Mean chlorophyll-a concentration vs. mean temperature for non-freezing period (Apr. – Nov.) of 1993 – 2002

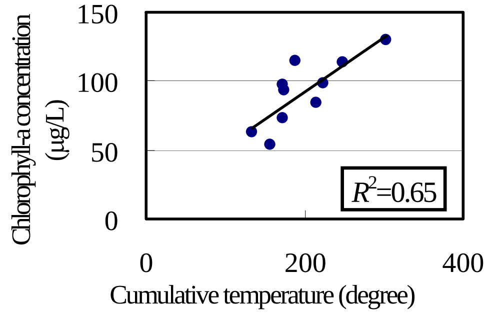

Fig. 10. Mean chlorophyll-a concentration for May. – Jun. of 1993 – 2002 vs. cumulative temperatures for Mar. – Apr. of 1993 – 2002

Table 1. Freezing duration settings

Setting	Freezing duration
Present	1/1～3/31
-10days	1/1～3/21
-20days	1/1～3/11
-30days	1/1～3/1

Table 2. Air temperature settings

Setting	Air temperature
Present	Observed value
+3 degree	Observed value+3degree
+5 degree	Observed value+5degree

sensitivity analysis. This figure shows that the mean chlorophyll-a concentration in non-freezing period (April – November) decreases with an increase in the air temperature like observed trends. To analyze chlorophyll-a concentration in connection with plankton species, Figure 12 shows the chlorophyll-a concentration of the three plankton species simulated by the model. According to the figure, as the temperature increases, the diatom species decreases, but the other two species in crease. The diatom species propagates at lower water temperatures than the other two species. Its propagation is restrained by temperature increase. These phenomena simulated by the model are likely to be occurring in the Barato River, where diatoms abound throughout the year.

Figure 13 shows the calculation results in spring (March – July) under present freezing duration and hypothetical shorter freezing duration. According to the figure, the chlorophyll-a concentration under the shorter freezing duration is higher than that under the present state. The chlorophyll-a concentration increases in May as the freezing duration decreases (Figure 14). These results suggest that the earlier end of the freezing due to air temperature increase in the snowmelt season induces increase of chlorophyll-a concentration in spring. Hence, it accounts for the results shown in Figure 10.

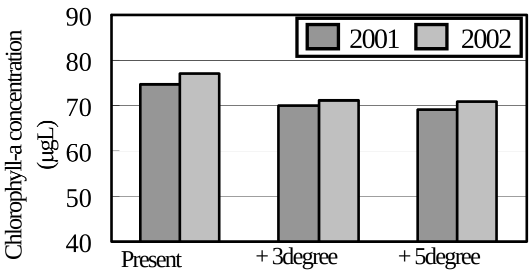

Fig. 11. Mean chlorophyll-a concentration for Apr. – Nov. under different temperatures

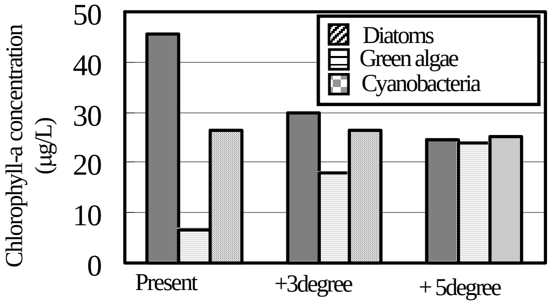

Fig. 12. Population of three plankton species under different temperatures (Apr. – Nov., 2001)

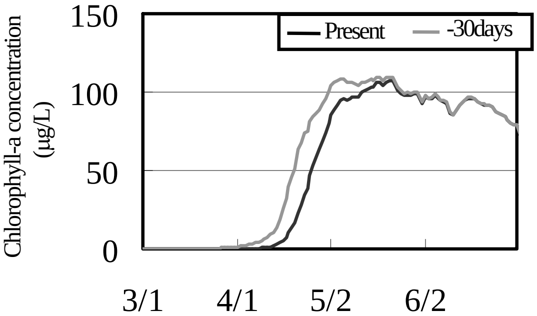

Fig. 13. Temporal changes in average chlorophyll-a concentration in the Barato River under different freezing durations (2001)

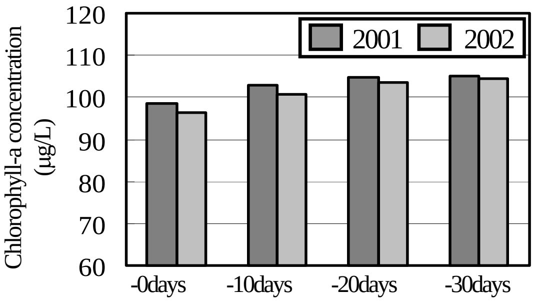

Fig. 14. Average chlorophyll-a concentration in the Barato River in May under different freezing durations

SUMMARY

The study found the following:

1) The water and substance budgets of the Barato River were quantified, and the features of the river, including stagnancy and the effects of water quality load origin, were clarified.

2) A water quality simulation was performed considering the features of the Barato River: complicated hydrological conditions (*e.g.*, influence of backwater of the mainstream and the existence of bottleneck for flow), and conditions specific to snowy cold regions (*e.g.*, increase in phytoplankton population due to snowmelt flood). The estimated results of the simulation were found to be accurate.

3) The proposed model was used to perform sensitivity analysis for different air temperatures and freezing durations. The results of the model agreed with the observed results. The model well explains the factors affecting water quality in snowy cold regions.

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RELATIONSHIP BETWEEN OVERWINTERING LOCATIONS OF CHERRY SALMON AND BED CONFIGURATION IN ICE-COVERED RIVERS

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ABSTRACT

The cherry salmon (*Oncorhynchus masou*) is an anadromous fish that spends its first year in rivers, and the river environment is very important to its growth. River freezing is the most difficult challenge for overwintering cherry salmon. Indeed, it is the main factor determining their survival. We conducted onsite surveys on the overwintering locations of cherry salmon and the riverbed conditions of such locations to identify a correlation between them. The surveys were conducted at the upper reaches of rivers, where successions of riffles and pools were present. It was found that the population of overwintering cherry salmon in pools and riffles can be determined by the local Froude number. Where the overwintering environment of fish had been understood only qualitatively, our findings have enabled some quantitative understanding of the overwintering environment of fish.

INTRODUCTION

The relationship between fish habitat and bed configuration has been investigated. It is known that pools and riffles are essential elements of the living environment for river fish. However, such investigations of this relationship have only been qualitative. It is thought that the relationship between fish habitat and bed configuration must be quantified, as must the relationship between hydraulic conditions and fish habitats. Based on field observations, Nogami and Watanabe showed that fish habitat (riffles and pools) can be classified quantitatively by local Froude number and water surface gradient in steep

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rivers. We decided to use this knowledge to understand the hibernation environment of a fish.

The cherry salmon is a common fish in Hokkaido. An anadromous fish, it spends its first year in rivers, whose environment is very important to its growth. Most rivers in Hokkaido freeze over in winter. Such freezing is the most difficult challenge for an overwintering cherry salmon. Indeed, it is the main factor determining its survival. We conducted onsite surveys on the overwintering locations of cherry salmon and the riverbed conditions of such locations to identify a correlation between them. This paper tries to express the overwintering environment of a fish as a physical index using local Froude number and water surface gradient.

FIELD OBSERVATION

Study sites

Onsite surveys on the overwintering locations of cherry salmon were conducted on the Sanru River (Fig. 1), a tributary of the Teshio River, at the five reaches in Fig. 2. The Hokkaido Development Bureau has been observing the population density of cherry salmon in the Sanru River (Table 1). Although the population density varies by year, the population density of each location relative each other location has the same tendency irrespective of year. We posited that the hibernation population relates to the population density in summer. Based on the population density in summer, we selected five reaches for observation of overwintering locations of cherry salmon. Reaches C and E were chosen as locations of high population density, and Reaches A, B and D were chosen as locations of average population density. Each reach was selected such as to include a riffle and an adjoining pool. Cells were established as the investigation units, by dividing the water surface into six in the transverse direction along an axis perpendicular to the streamline, and by dividing the water surface longitudinally at intervals of 2 to 5 m.

Table 1. Observation results of population density

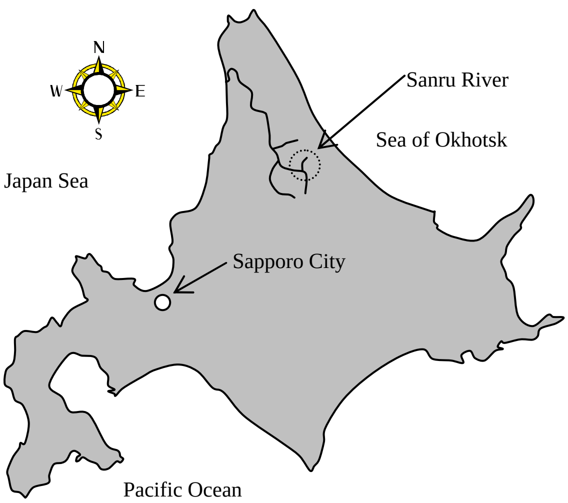

Fig. 1. Location of the Sanru River

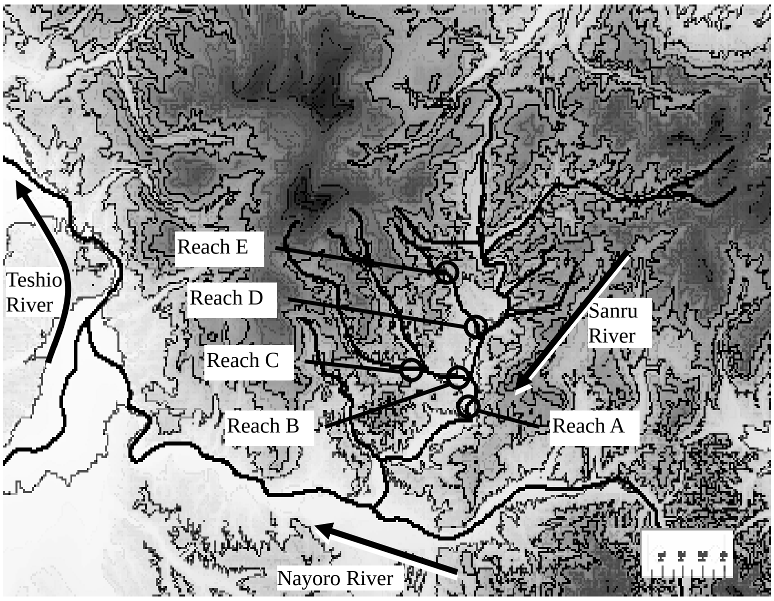

Fig. 2. Investigation points on the Sanru River

Reach	Population density (cherry salmon / m^2)				
	June ’00	June ’01	June ’02	June ’03	Avg.
A	0.23	1.30	0.31	1.64	0.87
B	0.76	1.20	0.77	1.11	0.96
C	1.03	1.49	1.53	1.94	1.50
D	0.85	2.04	0.42	1.79	1.27
E	4.13	1.89	0.79	2.11	2.23
F	0.33	1.03	0.26	0.73	0.59
G	0.13	1.20	0.09	0.87	0.57
H	0.47	1.47	0.38	2.10	1.11
I	2.14	0.57	0.74	2.99	1.61
J	0.26	0.21	0.11	0.31	0.22

Table 2 shows the size of the investigation section and Fig. 3 shows the longitudinal profile of water surface and bed elevations at each reach. The bed configuration, classified visually based on the observer’s experience, was also indicated. Seelbach (1987) reported that cherry salmon move to their overwintering sites when the water temperature drops below 5 . Observations were made during Nov. 26 to Dec. 2, 2003.

Table 2. Size of the observation section

Reach	Length of reach (m)	River width (m)	Longitudinal interval (m)
A	255	14.0~26.5	5
B	78	3.5~14.7	3
C	60	4.0~9.3	2
D	88	2.8~8.6	2
E	62	2.8~7.3	2

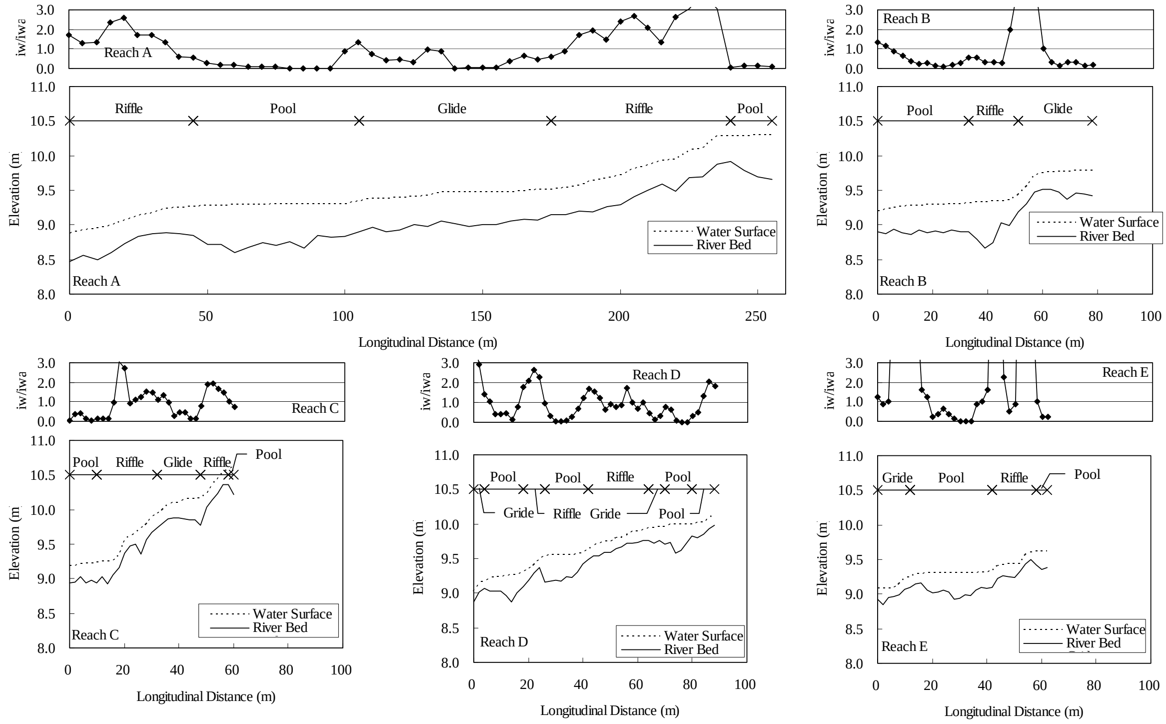

Fig. 3. Longitudinal profile of water surface and bed elevations, and i_w/i_{wa}

Observation method

Values recorded for each cell were water depth and flow velocity at the four corners of the cell, typical bed material size, and type of cover. Where the river depth was 0.3 m or less, the flow velocity was measured at 60%of the distance from the water surface to the riverbed. Where the river depth was 0.3 to 0.5 m, the flow velocity was measured at both 20% and 80%of that distance. Where the river depth was 0.5 m or more, the flow velocity was measured at 20%, 50% and 80% of that distance. The flow velocity and water depth averaged for the four corners of each cell were taken as the values of the cell. However, in pools at the riverbank, these were measured in the center of the cell. The bed material size was broken down into six classifications: base lock/sand (< 2 mm), gravel (2 to 30 mm), pebble (30 to 100 mm), cobble (100 to 250 mm), and boulder (> 250 mm). The cherry salmon were collected using electric shockers, with records made of the collection location, the number collected, and the length of each fish.

Observation results

The numbers of collected salmon are summarized in Table 3, and their lengths are summarized in Fig. 4. Since it is known that underyearling cherry salmon tend to be less than 10 cm in length, most of the cherry salmon were considered underyearlings.
The capture locations are shown in Fig. 5. The numbers in Fig. 5 are the number of collected salmon. Although most of the cherry salmon were collected near riverbank locations where cover was present, some were collected at the center of the river.

Table 3. Observation results

Reach	Date	Water temperature ( )	Number of collected salmon	Length of fish (cm)	Weight of fish (g)	Rate of underyearling (%)
A	’03 Nov. 26-28	2.0 – -3.2	492	6.3 (4.2 –10.3)	2.7 (0.6 – 11.2)	99.6
B	’03 Dec. 2	2.2	123	6.8 (4.4 – 12.5)	3.7 (0.8 – 20.2)	96.7
C	’03 Dec. 1	1.9	78	6.3 (4.4 – 10.3)	2.8 (0.7 – 12.7)	98.7
D	’03 Nov. 30	3.4	48	7.3 (4.9 – 12.8)	5.0 (1.1 – 25.8)	93.8
E	’03 Nov. 29	1.3	34	6.8 (4.7 – 9.6)	3.5 (1.2 – 8.3)	100.0

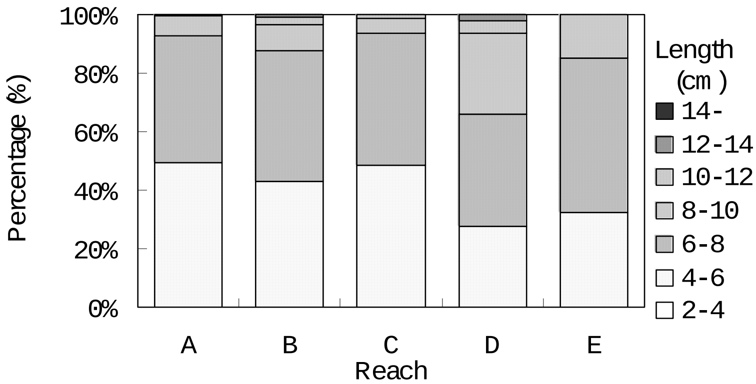

Fig. 4. Length of collected salmon in each reach

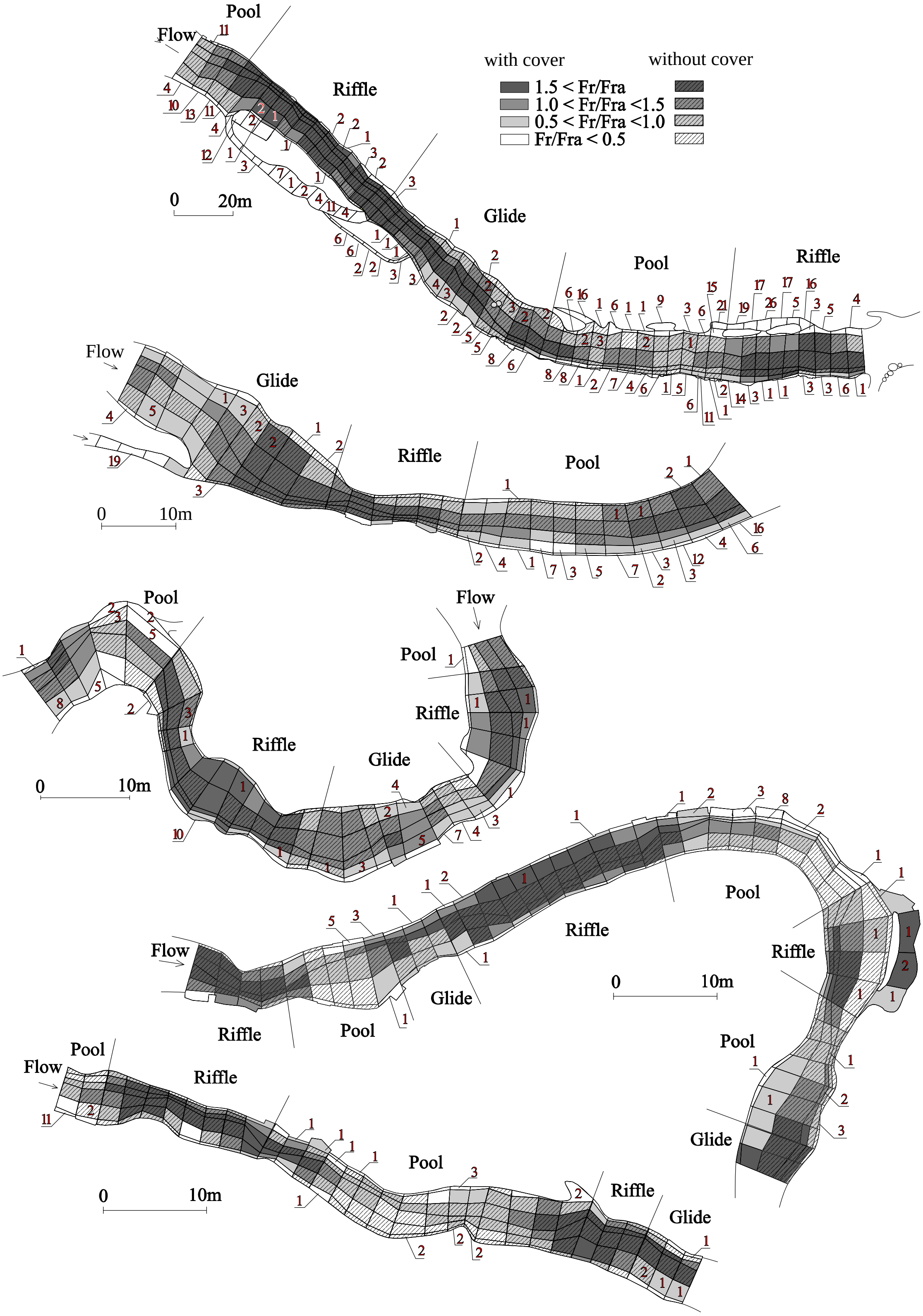

Fig. 5 Number of collecting salmon and flow condition at each cell

OVERWINTERING ENVIRONMENT

Quantitative classification of habitat

Nogami et al. (2003) reported that fish habitats can be quantitatively classified by i_w / i_{wa}, where i_w / i_{wa} of greater than 1 is riffle, less than 1 but greater than zero is glide, and approximately zero is pool. In their study, i_w is the water surface slope and i_{wa} is the water surface slope averaged for each reach. We plotted the longitudinal profiles of i_w / i_{wa} at each reach (Fig. 3) for comparison with the visual classification. The quantitative classification seems appropriate in the reaches studied in our investigation. However, it is hard to use i_w to express the habitat environment of the smaller cells. Since the Froude number has a relationship with i_w, the present paper uses F_r / F_{ra} as an index for classifying the physical environment (where F_r is the Froude number for each cell and F_{ra} is the Froude number averaged for a reach). F_{ra} of each reach is as follows: Reach A = 0.22, Reach B = 0.20, Reach C = 0.23, Reach D = 0.24, Reach E = 0.20. The rate of F_r/F_{ra} for each cell in each section classified visually is shown in Fig. 6. Visual classification of each section was done subjectively and holistically; therefore, the flow in each cell is not completely homogeneous even in the same section.

Moreover, the flow condition differs between locations near the bank and those at the center part of flow. Therefore, F_r / F_{ra} for each cell in the same section varies to some extent. However, there are many cells with a large value of Fr /Fra in the riffle, and the number of cells with a small value of Fr/Fra have increased in the pool. F_r / F_{ra} is large at riffles and small at pools. There is a tendency for cells where $F_r / F_{ra} > 1.5$ to become more numerous in riffles and to become less numerous in pools. This parameter can express the visual classification quantitatively.

Physical evaluation of overwintering environment

Population density of cherry salmon in each section divided by F_r / F_{ra} is shown in Fig. 7. The population density is classified also according to the presence of the water surface cover. The overwintering population density is high at cells where $F_r / F_{ra} < 0.5$ and the water surface is covered by vegetation. In general, cover is required for overwintering. However, even if cover is present, in places where F_r / F_{ra} is large, cherry salmon do not spend the winter, whereas in locations where F_r / F_{ra} is small, cherry salmon overwinter even when there is no over. Ideal overwintering locations for cherry salmon are those where cover exists and $F_r / F_{ra} < 0.5$.

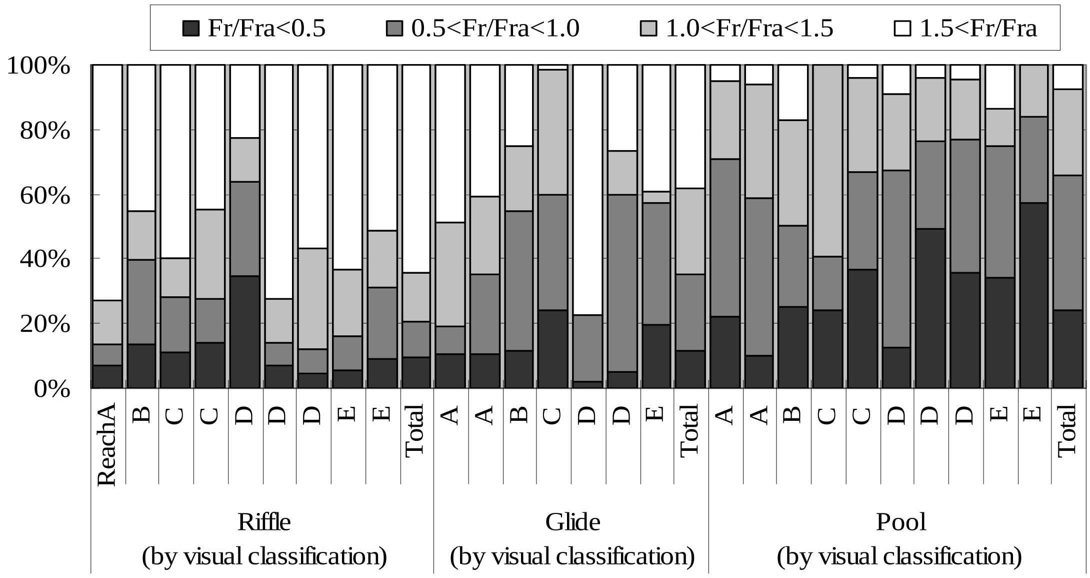

Fig. 6. Relationship between visual classification and classification indicator F_r/F_{ra}

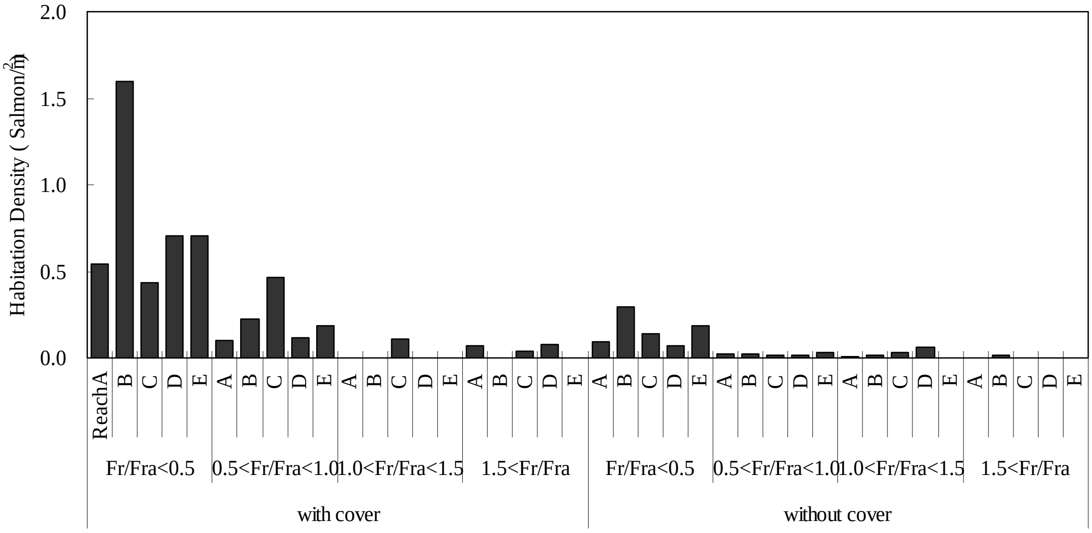

Fig. 7. Population density of cherry salmon in each section, by F_r/F_{ra}

CONCLUSIONS

Field observations were conducted to quantitatively clarify the overwintering environment of cherry salmon. Overwintering locations were found to those where cover is present and $F_r/F_{ra} < 0.5$. F_r/F_{ra} quantitatively expresses the visual classification and relates closely to the overwintering environment of cherry salmon. F_r/F_{ra} is decided by the flow condition and bed configuration. The bed configuration is formed at times of flooding. Cover is created by overhangs that form after bank erosion and by dead trees. The flow condition during flooding is very important to the overwintering environment.

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