Study on the mechanism of blue tide in Lake Abashiri and the measures to control it

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ABSTRACT

The mechanism of blue tide in Lake Abashiri in Japan and the measures to control it were investigated. As the lake water consists of two layers, upper one of fresh water and lower one of saline water, blue tide occurs when the lower water is conveyed to the surface by strong winds. The conditions that bring blue tide were made clear, and to keep the boundary level between -6 and -7 m is recommended to reduce the frequency of blue tide and to maintain the production of Japanese corbiculae. To prevent the intrusion of sea water, a weir with gate system was installed as an experiment at the exit of the lake. Experiments were carried out from January to March in 2006 and 2007. This system showed good performance, but the effect to the boundary was not satisfying. The procedures for improvement were discussed.

Keywords: blue tide, Japanese corbiculae, sea water intrusion, weir with gate system, brackish water

INTRODUCTION

Lake Abashiri is an inland sea lake located in northern part of Japan (Lat.44°00’ N, Long.144°10’ E). The location of the lake is shown in Figure-1, and the outline of the lake is listed in Table-1.

Table 1. Outline of Lake Abashiri

<table>
<thead>
<tr>
<th>Lake</th>
<th>Area</th>
<th>Depth Max.</th>
<th>Mean</th>
<th>Distance from estuary</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>km²</td>
<td>m</td>
<td>m</td>
<td>km</td>
</tr>
<tr>
<td></td>
<td>32.2</td>
<td>16.1</td>
<td>6.1</td>
<td>7.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Basin</th>
<th>Area</th>
<th>Land use (in 2003)</th>
<th>Agriculture</th>
<th>%</th>
<th>Forest</th>
<th>%</th>
<th>Stock farming</th>
<th>%</th>
<th>Urban</th>
<th>%</th>
<th>Others</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>km²</td>
<td></td>
<td>20</td>
<td>67</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Population (in 2002)</th>
<th>Human</th>
<th>Cow</th>
<th>Pig</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>37,695</td>
<td>22,000</td>
<td>64,000</td>
</tr>
</tbody>
</table>

Sea water began to intrude into the lake 80 years ago. The reasons of intrusion are multiple, and the river excavation between the lake and the sea done in 1926 is thought to be one of them. Due to the intrusion of sea water, lake water consists of two layers, upper one of almost fresh water and lower one of saline water. The intrusion of sea water has brought good conditions for the growth of Japanese corbiculae (Corbicula japonica).

On the other hand, blue tide was observed for the first time in 1987 and is occurring frequently, and also algal bloom has been observed more frequently since 1980. Blue tide has given much damage to a fishery. This paper consists of 3 sections such as characteristics of lake water quality, mechanism of blue tide, and experiments on the measures to control blue tide.

CHARACTERISTICS OF LAKE WATER QUALITY

The most important point concerning the water quality of Lake Abashiri is the existence of density stratification. Figure-2 shows typical vertical profiles of temperature, salinity, dissolved oxygen(DO) of lake water observed on the 27th July 2006, and Figure-3 shows that of nutrients such as nitrogen(N) and phosphorus(P). The profile of salinity indicates the existence of boundary of two layers at around -4 m. Nutrients concentration of the lower layer is 20 to 40 times of that of the upper layer.
Boundary level varies according to the flow to the lake and the sea water level. As an example, the annual change of boundary level and the flow to the lake from upper basin in 2005 is shown in Figure 4. Boundary level becomes higher from January to March because the flow to the lake is quite low. It becomes the highest usually in early spring just before a thaw. After a thaw, it becomes lower because of much increase of flow to the lake from upper basin.

To show the long-term change of the boundary, Figure 5 indicates the trend of boundary depth since 1926. Sources of nutrients were estimated as in Table 2. 55% of nitrogen in the upper layer originates from the basin and 45% from the lower layer or sediments of the lake. Whereas 80% of phosphorus originates from inside the lake.

Japanese corbiculae is the most important seafood in Lake Abashiri. Trend of a catch of Japanese corbiculae is shown in Figure 6. It increased in 1980s, and after around 1990 it is rather constant at around 800 t/year. The relationship between a catch of Japanese corbiculae and boundary level after 1975 is shown in Figure 7. The reason of
the increase between 1976 and 1985 may be the rise of boundary level. But the reason of the increase between 1986 and 1991 is thought to be something else, because boundary level had already risen around -6 m. Adding to Japanese corbiculae, several fish such as icefish and Japanese smelt are caught in the lake. A catch of major fishery is summarized in Table-3.

![Figure 6: Trend of catch of Japanese corbiculae.](image)

![Figure 7: Relationship between boundary level & catch of Japanese corbiculae.](image)

Table 3. Catch of major fishery in lake Abashiri (in 2001/2006)

<table>
<thead>
<tr>
<th></th>
<th>Weight (t)</th>
<th>Sales volume (milion yen)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Japanese Corbiculae</td>
<td>812/813</td>
<td>482/535</td>
</tr>
<tr>
<td>Japanese Smelt</td>
<td>142/182</td>
<td>68/79</td>
</tr>
<tr>
<td>Icefish</td>
<td>20.4/9.4</td>
<td>11/25</td>
</tr>
</tbody>
</table>

**MECHANISM OF BLUE TIDE OCCURRENCE**

Blue tide was observed for the first time in 1987, and it has been observed 19 times since then. Much fishery resources were killed by blue tide because of its lack of oxygen. As presented in the study of Muneta(2001), the occurrence of blue tide in Lake Abashiri is closely related to the boundary depth of two layers. And also the movement of lake water by strong wind is thought to have much relation to the occurrence of blue tide. So the conditions of boundary depth and wind velocity when blue tide was observed are summarized in Table-4.

To investigate the conditions which bring blue tide, the data of field survey and a multi-layer simulation model were utilized. The results are shown in Figure-8. If boundary depth is maintained around 6.0 m, the occurrence of blue tide can be suppressed up to wind velocity of 12.8 m/s (average of 3 hours), which considered to happen once every four years. And in case of 6.5 m, the probability of blue tide occurrence decreases to once every seven years.

From the viewpoint of the growth of Japanese corbiculae, upper layer water should be brackish to some extent. The study of Muneta(2001) showed that salinity more than 2.3 PSU is necessary for spawning of Japanese corbiculae under the water temperature of 22.5°C. So allowable lower limit of boundary depth is about 7 m which can be proposed from the data of Figure-7.

From this consideration, the target of boundary depth was determined to be 6 to 7 m. As the surface water level of the lake is usually between +0.2 to +0.5 m, -6 to -7 m is the target for boundary level to control.

**EXPERIMENTS ON THE MEASURES TO CONTROL BLUE TIDE**

Water quality conservation program for Lake Abashiri was established in 2004. Several projects such as wetland treatment, dredging of sediments, and sources management are listed in the program to control both blue tide and algal bloom. Among the projects to control blue tide, prevention of sea water intrusion to the lake was thought to be most useful.

A weir with gate system was selected as the measures to prevent sea water intrusion. Two types of
the system were compared, one is a weir with completely closed gate system (WCS), and the other is a weir with partially closed gate system (WPS). In both systems, gates are closed when sea water flows to the lake, and are opened when lake water flows to the sea. In WCS, upward flow of sea water is completely blocked when gates are closed. But in WPS, sea water can flow over a weir even gates are closed, because the level of top of weir is set to +0.2 m that is usually lower than high tide level.

![Figure 8: Calculated conditions of blue tide (Type: Spring & south wind)](image)

A full-scale experimental weir with gate system was installed at the exit of the lake. The experiment of WCS was done from January to March in 2006, and the experiment of WPS from January to March in 2007. The period of experiments were determined to consider the behavior of fish such as icefish, Japanese smelt, and salmon. Usually there is little fish that moves between the sea and the lake in this period.

The effect on the prevention of sea water intrusion by this system was estimated from the observed data of water level of the sea and the lake, and flow and salinity profiles at the exit of the lake. As a good linear relation is obtained between the upward flow and the maximum value of the difference of sea water level and the lake level during a tide, the quantity of intruded sea water can be calculated. The ratio of blockage of sea water intrusion by this system can be obtained when the data of the period using this system are compared with the data of the period without it. The results show that 88% of sea water flow to the lake and 98% of salts was blocked in WCS, whereas 76% and 96% respectively in WPS.

To understand and evaluate the effect by this system, a simulation model for boundary level was utilized. The model consists of two parts, saline water part and fresh water part. The distribution of intruded sea water into two parts and the diffusion of salinity from saline water part to fresh water part were calculated using the formula obtained from the observed data. Calculations for the cases with and without this system were implemented using the same data of inflow and sea water level. The results are shown in Figure-9. In WCS, the rise of boundary level was suppressed at the most 70 cm, and 32 cm in WPS to compare with the cases without weir.

![Figure 9: Effect of a weir with gate system on boundary level.](image)

From these results, a weir with gate system is considered to reduce the intrusion of sea water to the lake efficiently during the period of its operation. But the effect on boundary level was at most 70 cm by WCS, and it was not enough to reach to the targeted value of -6 m. We can conclude that this system can control the rise of boundary level, but further measures are expected.

To improve the performance, accurate simulation should be considered. For more accurate simulation, behavior of diffusion and advection of salts should be made clear. And it is important to estimate the effect of extension of operation period of a weir with gate system and flow out of saline water by flood. To prolong an operation period, the movement of fish between the lake and the sea should be secured.

**CONCLUSION**

The rise of boundary level of fresh water and saline water in Lake Abashiri has brought both the growth of Japanese corbiculae and the possibility of blue tide.

To suppress the occurrence of blue tide and to keep the growth of Japanese corbiculae, the boundary level should be maintained around -6 to -7 m. If the boundary level is maintained as mentioned above, the probability of the occurrence of blue tide will decrease to once every four to seven years.

A full-scale weir with gate system was installed as an experiment to control the intrusion of sea water to the lake. This system could reduce the intrusion of salts to the lake efficiently during the operation period, but it is not enough to lower the boundary level to the ideal position.

To maintain the boundary level at the ideal position, it is important to estimate the effect of extension of operation period of a weir with gate
system combined with flow out of saline water by flood through accurate simulation.

REFERENCES