

Influence of climatic warming on the amount of snow cover and water quality of Lake Biwa, Japan

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ABSTRACT. The amount of snow cover in the Lake Biwa catchment area has changed significantly from 1.9×10^{12} kg in 1974 to 0.3×10^{12} kg in 1979. The amount of snow cover was less in the warmer winter and when the amount of snow cover was less than 10^{12} kg, the average amount of snow cover in recent years, the lowest dissolved-oxygen concentration in the deep layer rapidly decreases. Climatic warming will significantly decrease the amount of snow cover in Lake Biwa catchment area and the dissolved-oxygen concentration in the deep layer of the lake, which may further enhance eutrophication of the lake.

INTRODUCTION

Lake Biwa, the largest lake and the most important freshwater resource in Japan, is located in Shiga Prefecture of Kinki district in central Japan. Some 13 million people in Osaka, Kyoto and several other municipalities depend on the water supply from Lake Biwa and its outflowing Yodo River.

The areas of Lake Biwa and its catchment area are 674 and 3174 km², respectively. The Lake Biwa catchment area is surrounded by mountain ranges of a little more than 1000 m a.s.l. The vast winter snow cover in the northern part of the catchment area is a very important water resource for Lake Biwa.

The water from melted snow has a high concentration of dissolved oxygen. In years when the amount of snow cover is meager, dissolved-oxygen concentration becomes significantly low in the deep layer, or hypolimnion, of the lake. This indicates that snow cover plays an important

role in sustaining the dissolved-oxygen concentration and maintaining the water quality of Lake Biwa.

It is reported that annual average air temperature will increase by 1.5°–3.5°C in Japan by the 2030s (Japan Meteorological Agency, 1989), while Tegart and others (1990) estimate a rise of global average air temperature by 1.5°–4.5°C between 2025 and 2050 when the CO₂ concentration will be double. Presuming this to be the case, we here investigate what will happen to the amount of snow cover in the Lake Biwa catchment area and the dissolved-oxygen concentration of Lake Biwa.

AMOUNT OF SNOW COVER

The amount of snow cover is defined in this paper as the total precipitation in the form of snow in the Lake Biwa catchment area (Fushimi, 1983).

Figure 1 indicates, from 1968 to 1983, annual

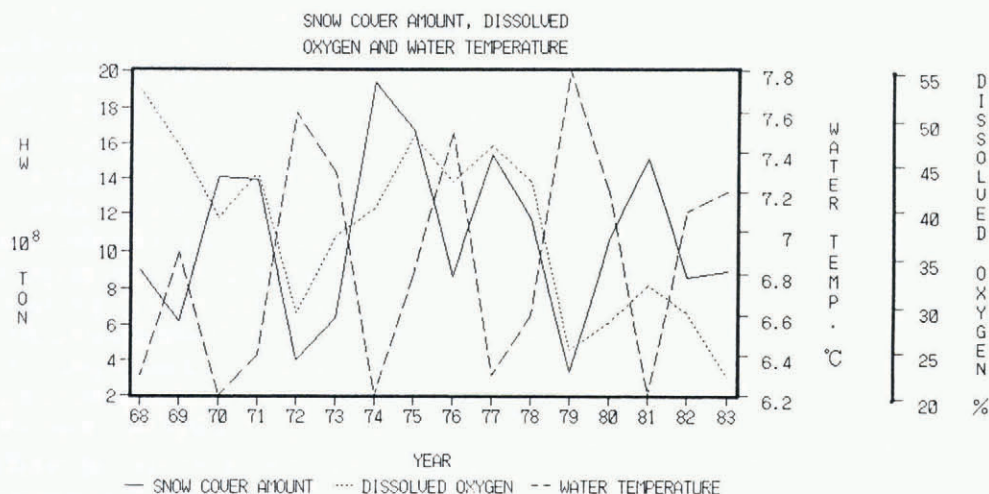


Fig. 1. Amount of snow cover in the Lake Biwa catchment area, lowest dissolved-oxygen concentration, and minimum water temperature of the deep layer of Lake Biwa. HW: amount of snow cover.

variation in the amount of snow cover, the lowest dissolved-oxygen concentration just before the overturning period in the beginning of winter (as a per cent of saturation), and the minimum water temperature of the deep layer of the central part of Lake Biwa at the end of winter season (Fushimi, 1991).

The amount of snow cover in the Lake Biwa catchment area fluctuates from 0.3×10^{12} kg in 1979 to 1.9×10^{12} kg in 1974 with a mean of 1.03×10^{12} kg. When the amount of snow cover is above the mean, a lower water temperature and higher dissolved-oxygen concentration are observed. This is caused by the density current of melted snow subsiding from the river mouth into the deep layer of Lake Biwa. The amount of snow cover affects the dissolved-oxygen concentration, the water temperature and the eutrophication process in Lake Biwa.

Figure 2 shows the relationship between the amount of snow cover and the average winter air temperature from December to March at Hikone in the central part of the Lake Biwa catchment area. The amount of snow cover is less in a warmer winter but greater in a colder winter. The amount of snow cover decreases by 0.48×10^{12} kg with an increase of 1°C in the average winter air temperature. Therefore, there is strong possibility that climatic warming will significantly reduce the amount of snow cover. However, the decrease in the amount of snow cover must be considered in relation to a concomitant increase of precipitation and rise of snowline altitude in response to climatic warming.

DISSOLVED-OXYGEN CONCENTRATION

The depletion of dissolved-oxygen concentration in the deep layer of Lake Biwa was first reported by Naka (1973). Since then, similar results have been observed by

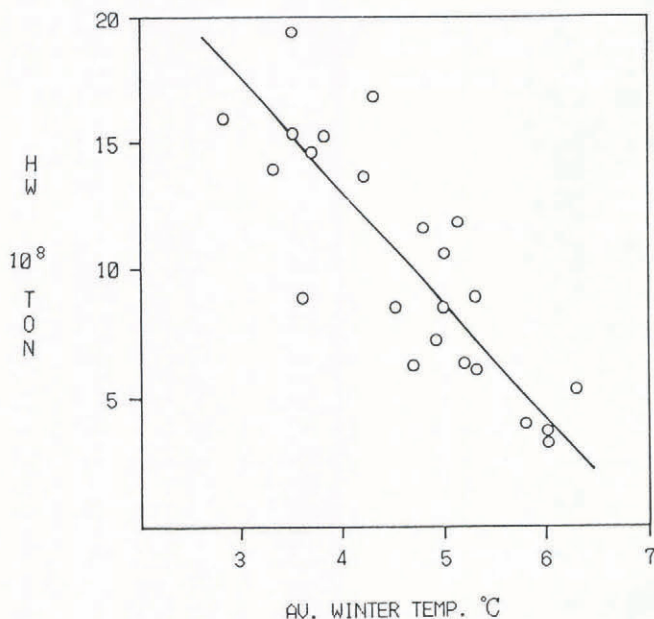


Fig. 2. Relationship between snow-cover amount and average winter air temperature. HW: amount of snow cover.

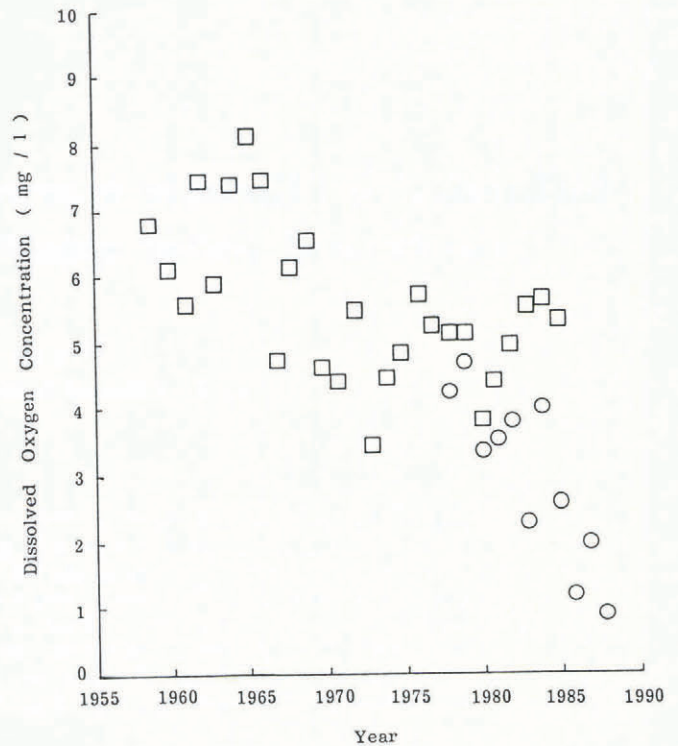


Fig. 3. Lowest yearly dissolved-oxygen concentration over a 35yr period in a hypolimnion of Lake Biwa. Squares indicate data observed by Shiga Prefectural Fisheries Experimental Station and circles that observed by Shiga Prefectural Institute of Public Health and Environmental Science.

the Shiga Prefectural Institute of Public Health and Environmental Science. Okuda and others (1987) and Kumagai (1988) found that the depletion of dissolved oxygen is caused not only by eutrophication, but also by the decrease of snow cover.

Figure 3 shows the yearly lowest dissolved-oxygen concentration measured in the deep layer of Lake Biwa from 1958 to 1988. The measurement, made by Shiga Prefectural Fisheries Experimental Station and Shiga Prefectural Institute of Public Health and Environmental Science, was taken at the depth of ~ 80 m in October and November, just before the overturning period when the concentration of dissolved oxygen in the deep layer reaches its minimum (Kumagai and Fushimi, in press).

Lake Biwa has suffered from eutrophication since the 1960s and the dissolved-oxygen concentration in the deep layer of Lake Biwa has gradually decreased. If this decrease of the dissolved-oxygen concentration continues, anoxic conditions may prevail by the end of this century, allowing release of ammonia and phosphates, etc., from the lake-bottom sediments. Therefore, it is important to halt the lowering of the dissolved-oxygen concentration.

Figure 4 shows the relationship between the amounts of snow cover and the lowest dissolved-oxygen concentrations. When the amount of snow cover is less than 10^{12} kg, the dissolved-oxygen concentration in the deep layer of Lake Biwa rapidly decreases. However, when the amount of snow cover is greater than 10^{12} kg, the dissolved-oxygen concentration remains high. This means that a critical amount of snow cover of approximately 10^{12} kg, the average amount of snow cover in recent years, is necessary

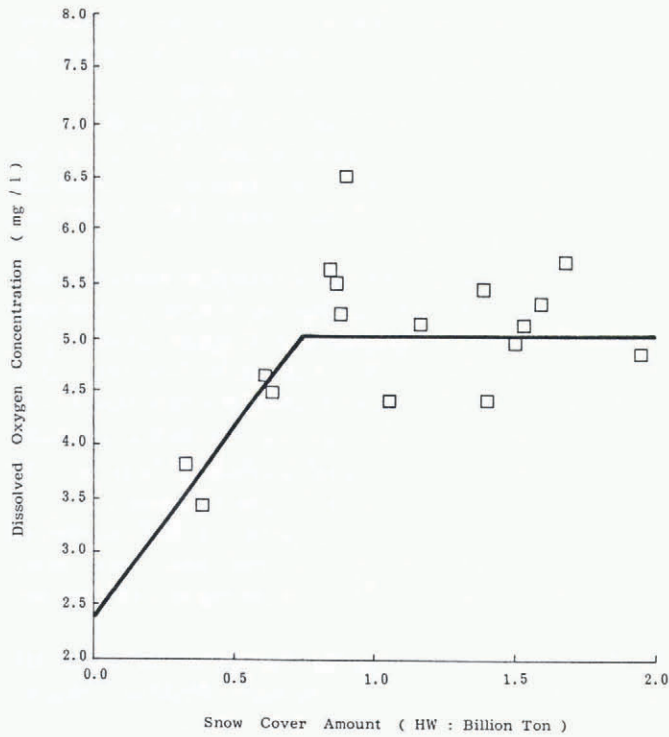


Fig. 4. Relationship between snow-cover amount and the lowest dissolved-oxygen concentration.

to sustain the dissolved-oxygen concentration in the deep layer of Lake Biwa.

DISCUSSION

Figure 5 shows an average altitudinal distribution of snow-cover amounts up to 1400 m a.s.l. in the Lake Biwa catchment area. The solid line represents present-day conditions and the other curves show times of climatic warming with increase of precipitation of 10%, 20%, 30%, 40% and 50% (Fushimi, 1991). There is a possibility that the amount of water vapor in the atmosphere will increase with climatic warming.

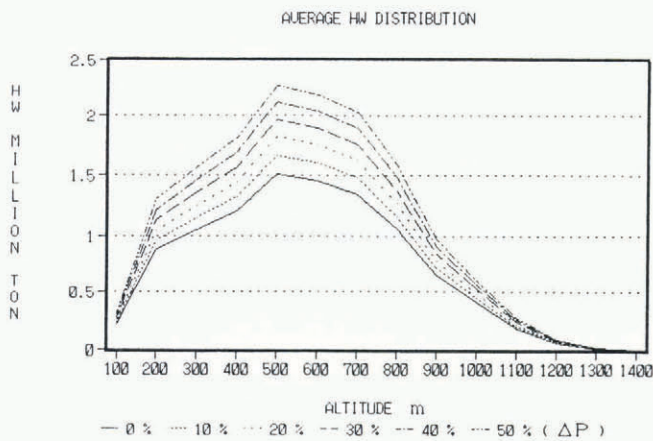


Fig. 5. Average altitudinal distribution of snow-cover amount in the Lake Biwa catchment area and possible increases due to hypothesized increases in precipitation. HW: amount of snow cover.

Due to topographic conditions, the greatest amount of snow cover is stored at altitudes 400–800 m a.s.l. With climatic warming, the possibility of precipitation will increase and, at the same time, the altitude of the average snowline will rise. That is, the boundary altitude between rain and snow will be raised by climatic warming and the rise in snowline altitude will decrease the amount of snow cover. The amount of snow cover at the time of climatic warming must be estimated based on the variations in the amount of precipitation and the altitude of the average snowline.

Since a rise in the average snowline altitude is estimated by a temperature lapse rate of $0.67^{\circ}\text{C } 100\text{ m}^{-1}$ in the Lake Biwa catchment area, the amount of snow cover is estimated to be zero at an area below the snowline altitude when the climatic warming proceeds. On the contrary, there will possibly be more snow cover at higher altitude due to an increase in precipitation. Therefore, the total amount of snow cover at higher altitude is calculated by the average altitudinal distributions of snow cover reflecting increases in precipitation of 10%, 20%, 30%, 40% and 50% (Fig. 5).

Figure 6 shows the amount of snow cover estimated in relation to the increase in precipitation in the y-axis (%) and that of the average air temperature in the x-axis ($^{\circ}\text{C}$) under conditions of climatic warming. The shaded part shows that the amount of snow cover is less than 10^{12} kg , or an approximate average in recent years, and the unshaded part greater than 10^{12} kg .

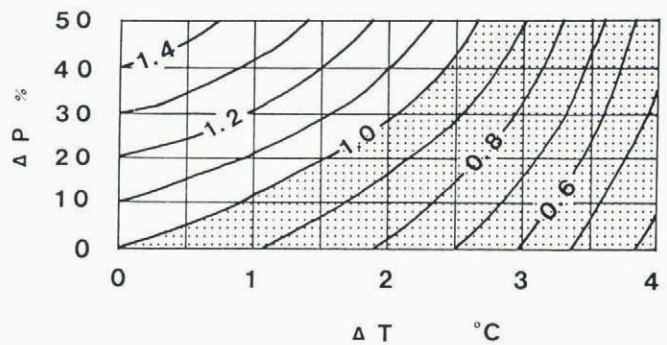


Fig. 6. Amount of snow cover estimated from an increase of precipitation (%) and average air temperature ($^{\circ}\text{C}$). The amount of snow cover is indicated by a unit of 10^{12} kg .

It is reported that an average air temperature will increase by $1.5^{\circ}\text{--}3.5^{\circ}\text{C}$ by the 2030s. If the average air temperature increases by 1.5°C , the amount of snow cover would not be more than 10^{12} kg , unless the amount of precipitation is more than 20% in excess. If the average air temperature rises by 3.5°C , the amount of snow cover would decrease significantly to about 0.6 and $0.7 \times 10^{12}\text{ kg}$, even if the precipitation is, respectively, 20% and 40% in excess.

Since the inclinations of the snow-cover isogram curves become steeper when the average air temperature rises more than 3°C , the more climatic warming proceeds, the less the amount of snow cover is. This is due to the topographic conditions in which the area 400–800 m a.s.l., where a large amount of snow cover in Lake Biwa catchment area is usually stored, becomes lower than the

average altitude of the snowline under climatic warming.

Consequently, climatic warming could significantly decrease the amount of snow cover in the Lake Biwa catchment area and the dissolved-oxygen concentration in the deep layer of the lake, which may further enhance eutrophication of Lake Biwa. From the viewpoints of water quantity as well as water quality, we will face a difficult time making rational use of the water resources of Lake Biwa in the 21st century with predicted climatic warming.

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The accuracy of references in the text and in this list is the responsibility of the author, to whom queries should be addressed.