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IMPACT OF MIGRATORY WATERFOWL FLOCKS ON WATER QUALITY OF A LAGOON

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Abstract

In this work, we estimated nutrient loading from waterfowl droppings into Sakata Lagoon, which was registered as a "Ramsar Site" in 1996. The total phosphorus (TP) and nitrogen (TN) loadings caused by flocks of overwintering waterfowl in the lagoon were estimated to be 0.8 kgP/d and 3.62 kgN/d, respectively. Increases of TP and TN concentrations in the lagoon waters by waterfowl during the wintering period were found to be 80% and 25%, respectively. Comparative analysis suggested that during winter, daily phosphorus loading by waterfowl exceeded that from groundwater and approximately equaled the daily loading from sediment release. Moreover, the lagoon's responses to different phosphorus sources were discussed.

KEYWORDS: *migratoty waterfowl, nutrient loading, Sakata Lagoon, potential toxicity*

1. Introduction

Migratory waterfowl play an important role in several spheres of human interest: culturally, socially, scientifically and as a food resource. The bird's ability to navigate long distances migrating across continents and arriving and departing in tune with the seasons sparks our imagination and enriches our appreciation of the natural world. In meeting the demands of their life cycles, waterfowl depend on high-quality wetland habitats in many countries. Conservation efforts directed towards migratory waterfowl can provide an important mechanism to promote the conservation of our wetlands and other habitats across the world. The Ramsar Convention of 1971 is an intergovernmental treaty that provides a framework for national action and international cooperation to promote conservation and wise use of wetlands and their resources (King, 1983). By 2007, the registered Ramsar sites totaled 1,674 and the number of sites in Japan has reached to 33 (Registered Ramsar Sites in Japan, 2007). However, due to direct habitat loss through changes in land utilization practices and indirect loss through environmental quality degradation, the remaining wetlands might not be able to support flocks of birds sustainably. According to the Geographical Survey Institute of Japan, the overall area of wetlands in Japan has decreased by 60% since the Meiji era. However, the number of swans flying to Japan during the winter has risen in recent years (Figure 1). Therefore, whether or not shrinking wetlands in Japan can support migratory waterfowl flocks in the long run is

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an important question to answer. This question comes from the fact that waterfowl can cause water quality problems when their populations are large relative to the size or volume of the water body. Manny et al. (1975) documented that 3,000 Canada geese on a 15 ha pond turned it hypereutrophic. Gould and Fletcher (1978) measured the nutrient content of feces from five species of gulls and concluded that gulls present in large numbers were capable of moderately affecting surface water quality. Post et al. (1998) attempted to estimate nutrient inputs from geese into National Wildlife Refuge (NWR) wetlands in New Mexico, USA near the Rio Grande. Their field observations and model simulations indicated that about 40,000 Lesser Snow Geese and Ross's Geese excreted a total of more than 15,000 kg N and nearly 1,800 kg P in the NWR during the period of November to mid-March, 1995/1996. Bird droppings were also thought to stimulate the growth of bacteria and algae in open drinking water reservoirs in Seattle, Washington, USA (Bonoff and Donnelly, 1995). Despite the evidence in the literature, nutrient additions by waterfowl to enclosed or semi-enclosed water bodies have not received sufficient attention in formulating Total Maximum Daily Load (TMDL) management limits. In Japan, the role of waterfowl in enclosed water bodies' nutrient cycling was often thought to be either unimportant or beneficial because aquatic birds helped purify water (Kuwae, et al. 2003).

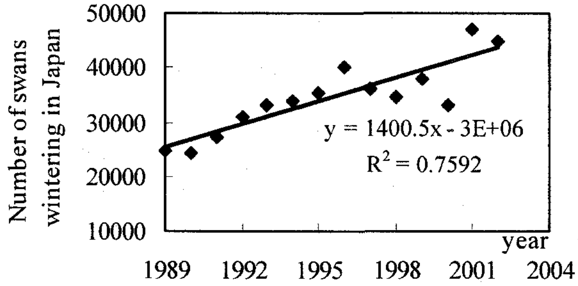


Figure 1 Increase in the number of swans wintering in Japan (source: Internet Nature Research Institute)

In the present study, we estimated waterfowl-contributed nutrient loading into a eutrophic lagoon water and examined the response of the lagoon to migratory waterfowl flocks. The objective was to use a case study in Japan to highlight the need to consider waterfowl for better management of lakes and lagoons and provide a call for further study. Small lakes, wetlands and lagoons are apparently susceptible to waterfowl effects. Therefore, considering and quantifying both waterfowl-contributed nutrient loading and the responses of different water bodies is particularly important for wise and sustainable use of relatively small water bodies around the world. It should be mentioned that the estimation of waterfowl-contributed nutrient loading in Sakata Lagoon has been published in Japanese literature (Huang and Isobe, 2007). However, contributions by waterfowl to the winter daily increases of TP and TN concentrations in the lagoon waters were recalculated in a refined way in this study. Moreover, the comparison of waterfowl-contributed phosphorus loading to other sources was conducted and the lagoon's responses to different phosphorus sources were examined.

2. Study site

The study site is Sakata Lagoon, located in the Akatsuka district in southwestern Niigata, 37°49' N in latitude and 138°53' E in longitude (Figure 2). Sakata Lagoon and its surrounding area was designated as a special district for bird protection under the Natural Parks Law in 1981, and was also registered as a "Ramsar Site" in 1996. It is home to migratory birds such as swans and bean geese. Sakata Lagoon is a sand dune lake formed on a low land between the sandbanks of Niigata Sand Dune. The surface area of the lagoon is approximately 436,000 m^2 and is situated 5 m above sea level. Averaging 1 m, the lagoon is quite shallow and the bottom is generally flat (Figure 3). There is no river flowing into the lagoon, and it collects water from rainfall and springs in the surrounding sand dunes. The overall water budget (Figure 4) clearly shows that Sakata Lagoon is a predominantly groundwater-fed water body.

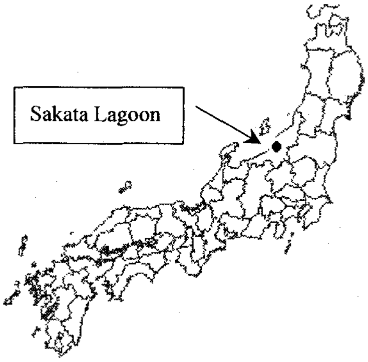


Figure 2 Geographic location of Sakata Lagoon

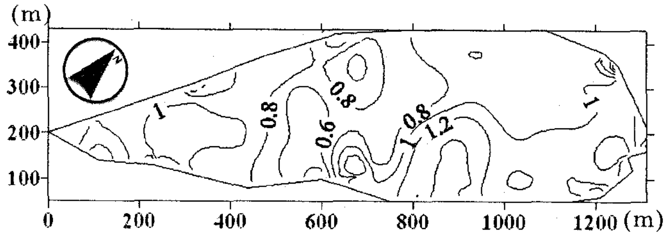


Figure 3 Depth contour of Sakata Lagoon

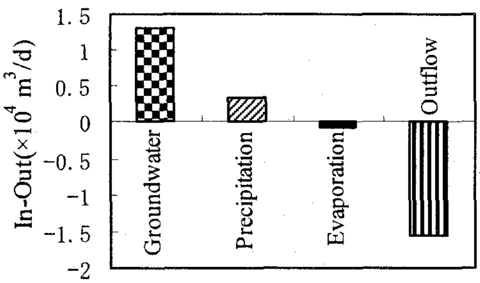


Figure 4 Water budget for Sakata Lagoon (source: Niigata City Office)

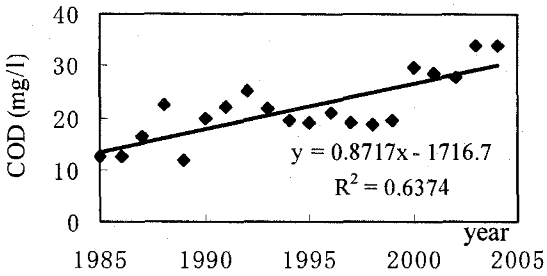


Figure 5 Annual variations of COD in Sakata Lagoon (source: Niigata City Office)

According to the Niigata City Office, a total of 157 species of birds, belonging to 37 families of 17 orders, have been observed in the Sakata Bird Sanctuary. In particular, there are 73 species of water birds, including wild geese, ducks, shore birds, herons and great reed warblers, which account for 46% of all the birds observed in Sakata Lagoon. Every winter, some 3,000 swans, 5~10% of the total number of swans flying to Japan, and a large number of other water birds, such as white-fronted geese and bean geese, also fly to winter in Sakata Lagoon.

Despite Sakata Lagoon's invaluable ecological resources and various efforts to protect them, the Sakata Lagoon environment has been deteriorating over the past decades. The use of fertilizer in surrounding farmlands has led to high concentrations of nutrients in subsurface water supplied to the lagoon (Niigata City, 2005). Figure 5 shows the annual variation of the chemical oxygen demand (COD) of the lagoon waters for the period of 1985~2004. A rising trend is obvious. Figure 6 shows the characteristics of monthly variations of phosphorus and nitrogen concentrations measured by the

Niigata City Office.

For better understanding the environmental conditions in the lagoon, Huang (2005) conducted a field investigation on the spatial and temporal variability of water quality in the lagoon and revealed that the lagoon can be classified as being highly eutrophic in terms of phosphorous and Chlorophyll-a (Chl-a) concentrations and the Secchi depth. In addition, the release rates of phosphorus from lagoon sediments under both aerobic and anaerobic conditions and the sediment oxygen demand were obtained experimentally from that study.

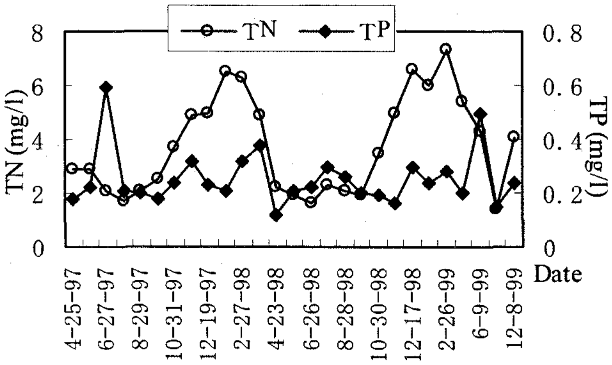


Figure 6 Monthly measured phosphorus and nitrogen concentrations (source: Niigata City Office)

3. Methodology

3.1 Target year

As shown in Figure 7, 3,000~5,000 Tundra swans (*Cygnus columbianus*) flew to Sakata Lagoon for wintering beginning in November each year. This study focused on daily loading from aquatic birds during December 1998, when the number of wintering birds was relatively low compared to other years. Focusing on the winter of 1998 avoided overestimation because it was the least severe case. Table 1 gives the numbers of different birds observed in Sakata Lagoon on January 15, 1999, which was considered as being representative for the winter period from December 1998 to January 1999. Also shown in Table 1 is the weight range for each species.

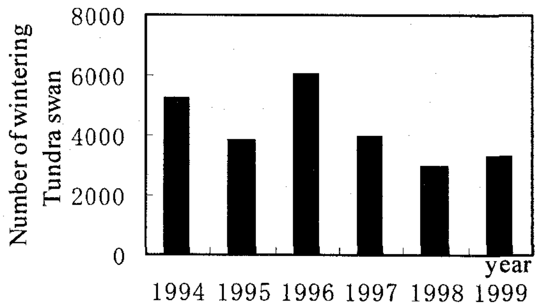


Figure 7 Number of Tundra swans wintering in Sakata Lagoon (From November of each year to February of the next year) (source: Niigata City Office)

3.2 Formulation of nutrient loading estimation

The daily nutrient loading to Sakata Lagoon from waterfowl was estimated from three data sources: (a) the number of birds observed; (b) the production rate of droppings and (c) the nutrient content of bird feces. The following equation estimates daily nutrient loading by bird droppings:

$$BL = C_r \times N \times DW \times NC \tag{1}$$

where *BL*=nutrient loading rate (kg/d); *N*=number of waterfowls; *DW*=dry weight of droppings per bird per day (kg/d); *NC*= nutrient content of droppings as a percent of dry weight (%); C_r=probability that droppings enter the target water body.

Since gastrointestinal tract anatomies and metabolic processes were similar among waterfowl, dry weight of droppings (*DW*) from all species was assumed to be 2.25% of their body weight according to Sanderson (1978). It was also implicitly assumed that aquatic birds resembled each other in their food choices and behavior, which was supported by previous research (NRC, 1984). Manny et al (1994) reported that the phosphorus content of dry goose droppings was 1.5%±0.5% of their dry weight. However, measurements by Nakamura (2002) indicated that grain-fed ducks produced droppings with phosphorus contents equivalent to 0.33% of their dry weight. In this study, Nakamura's value was chosen for *NC* because the study was conducted in Japan, and may better reflect the locality. The nitrogen nutrient content of droppings was taken to be 1.46%, also from the experiment of Nakamura (2002).

Because bird feces may enter the water or may be dropped on coastal land, a probability factor was introduced to account for this variability. Our observations found that waterfowl stayed in the water or along the shore line for about 7~8 hours each day. Assuming the probability that droppings enter the target water body was proportional to the time the waterfowl utilized the waters, the factor C_r was set to be one third in this study.

Table 1 Numbers of different wintering birds observed in Sakata Lagoon on January 15, 1999 and the range of weight for each species (source: Niigata City Office)

Species	Number	Weight (kg)
Tundra swan (*Cygnus columbianus*)	2,224	4～8
Whooper Swan (*Cygnus Cygnus*)	39	8～12
Mallard (*Anas platyrhynchos*)	12,736	0.75～1.35
Spotbill Duck (*Anas poecilorhyncha*)	231	0.75～1.35
Common Teal (*Anas crecca*)	1,281	0.32～0.33
Bean goose (*Anser fabalis*)	68	2.4～4.4
White-fronted Goose (*Anser albifrons*)	17	1.9～2.7
European Pochard (*Aythya ferina*)	109	0.9～1.1
Smew (*Mergus albellus*)	111	0.52～0.93
Pintail (*Anas acuta*)	22	0.76～1.25

3.3 Potential toxicity evaluation

According to Nakamura's experiment, feces of grain-fed ducks are easily converted to ammonia once they enter the water. Ammonia exists in two forms in natural waters: ammonium ion (NH^+_4) and ammonia gas (NH_3). Whereas the former is innocuous at the levels encountered in most natural waters, the latter, unionized form is toxic to fish (Thurston and Russo, 1978; Yamagata and Niwa, 1982). The NH_3 concentration depends on a number of factors in addition to the total ammonia concentration (Emerson et al., 1975; Messer et al., 1984). The most important factors include pH and temperature; the concentration of NH_3 increases with increasing pH and with temperature. At high pH, ammonia exists principally in the toxic, unionized form. The fraction of total ammonia in the unionized form (F (%)) can be calculated as below (Chapra, 1997):

$$F = \frac{1}{1 + \frac{10^{-pH}}{10^{-pK}}} \qquad pK = 0.09018 + \frac{2729.92}{T_w(kelvin)} \tag{2}$$

where T_w is the water temperature in Kelvin.

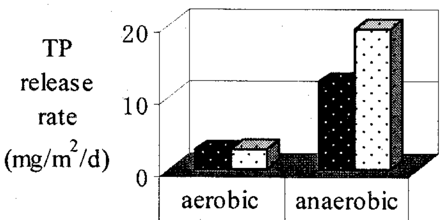
In this study, we looked into the potential bird-related toxicity by examining the level of NH_3 according to the measured pH during winter in the lagoon and by referencing to EPA's criteria.

3. 4 Comparisons to other phosphorus sources

So far, ground water and nutrient release from sediment were considered to be major nutrient sources to Sakata Lagoon. For the purpose of comparison, phosphorus loadings due to groundwater and sediment release were also estimated as described below.

Based on the survey conducted by the Niigata City (internal report on groundwater around Sakata Lagoon, 1998, 1999), the monthly-averaged daily phosphorus input from groundwater was obtained by multiplying the monthly-averaged daily groundwater volume with the spatial average of monthly well-point-sampled phosphorus concentrations around the lagoon.

On August 23, 2004, sediment samples were taken from both the north and south areas of the lagoon. The release rate of total phosphorus (TP) from sediment samples collected on the lagoon bottom was analyzed under both aerobic and anaerobic conditions (Huang, 2005). Figure 8 indicated that the release rate of TP was quite high under anaerobic condition. Meanwhile, sediment



	aerobic	anaerobic
■ South	2.7	12.2
□ North	2.8	19.7

Figure 8 TP release rate from sediment (source: Huang, 2005)

oxygen demand (SOD) was experimentally estimated to be approximately 10 $g \cdot O_2/m^2/d$ (Huang, 2005). In normal years, about 80% of the water surface of Sakata Lagoon was covered by emergent macrophytes in July and August. Our field survey found that the dense vegetation generated weak temperature stratification which led to anaerobic conditions (Huang, 2005). Assigning the whole lagoon the averaged anaerobic release rate for July and August and the aerobic release rate to other months, the monthly mean daily internal loading of phosphorus was calculated by multiplying the monthly averaged surface area with the release rate for each month.

4. Results

4.1 TP and TN loadings by waterfowl

Inserting the values given in Table 1 into Eq. (1), the daily total phosphorus and nitrogen loadings to Sakata Lagoon by birds dropping were estimated to be around 0.8 kg/d and 3.62 kg/d, respectively. Converted to concentrations by dividing the loadings with the mean water volume for December 1998, which was 160,000 m^3, the daily increases in phosphorus and nitrogen concentrations due to the loadings were found to be 0.005 mg/l per day and 0.023 mg/l per day, respectively.

By fitting a third order polynomial to the measured nutrient concentrations of October, November, December and subsequent January as shown in Figure 9, the daily nutrient concentration increase in December can then be calculated by taking the derivative. Considering interannual variability, this process was repeated for three years; 1995, 1997 and 1998 in light of data consistency. Then the average was taken. Figure 10 compares the averaged daily phosphorus and nitrogen concentration increase rates determined in the above-mentioned way and that estimated from waterfowl counts. Bird droppings accounted for 80% and 25% of the observed winter daily increases of phosphorus and nitrogen, respectively. In other words, bird droppings exerted more influence on phosphorus than on nitrogen. This may be explained by the fact that groundwater entering the lagoon from surrounding radish and watermelon fields has a very high nitrogen concentration, thus playing a dominant role in the nitrogen cycle of the lagoon.

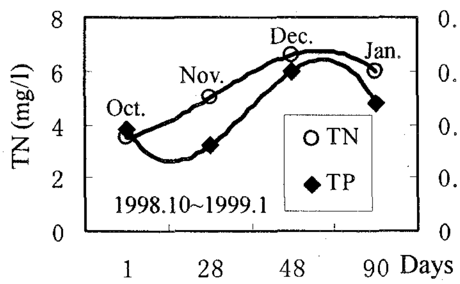


Figure 9 Curve-fitting the nutrients variations in winter season

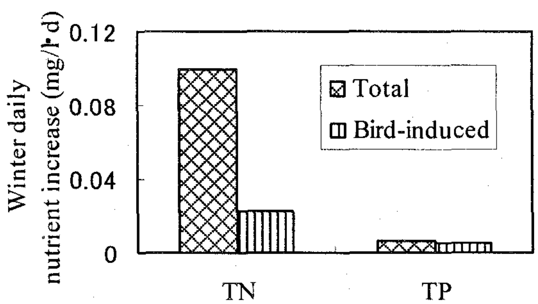


Figure 10 Contribution of bird droppings to the daily increase rates of nutrients during December 1998

4.2 Potential toxicity in winter

Figure 11 shows the monthly means of pH and water temperature in 1998. In December, pH and water temperature were 8.8 and 6.8, respectively. Inserting these values in to Eq. (2), the fraction of NH_3 in December was found to be 10%. Figure 12 depicts annual variations of December's pH and Chl-a concentration over a decade. In four winters out of eleven, pH was close to 9. The high winter pH was attributable to high level of winter phytoplankton activity as manifested in Chl-a concentration. According to EPA's ammonia criteria document (1985), the one-hour-average concentration of NH_3 should not exceed more than 0.13 mg/l or the four-day average of NH_3 should not exceed more than 0.025 mg/l, if the water temperature and pH were given to be 10 °C and 9, respectively. In the winter of 1998, the concentration of NH_3 was not measured. However, NH_4 data were available from the Niigata City Office for winters from 1993 to 1996. The minimum, averaged and maximum values of all winter NH_4 data from 1993 to 1996 were 0.1 mg/l, 0.48 mg/l and 1.8 mg/l, respectively. If this can be considered as a representative range for winter NH_4 concentrations in Sakata Lagoon, the concentration of dissolved un-ionized ammonia (NH_3) could vary up to 0.18 mg/l with 0.05 mg/l being average since the ratio of NH_3 to NH_4 was one ninth. This simple inference, together with the increasing trend of winter pH values in the lagoon, suggested that bird droppings did not only contribute to the nitrogen level in Sakata Lagoon, but they might also cause toxicity in the lagoon waters. The fact that the potential toxicity in Sakata Lagoon might occur in winter is because the fraction of total ammonia in the unionized form is more sensitive to pH than water temperature.

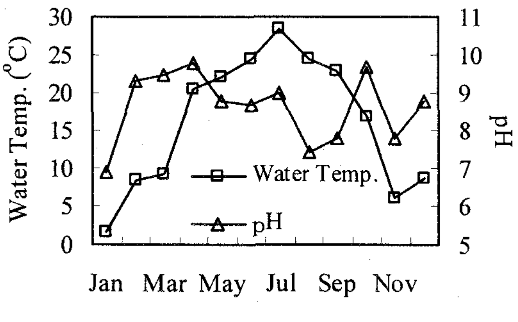


Figure 11 Monthly variations of water temperature and pH in 1998 (source: Niigata City Office)

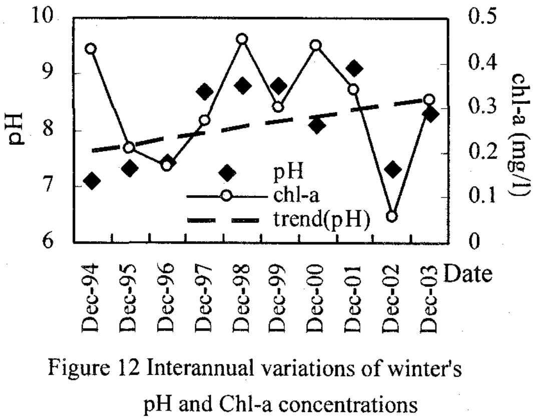


Figure 12 Interannual variations of winter's pH and Chl-a concentrations (source: Niigata City Office)

4. 3 Importance of bird-contributed phosphorus loading in relation to other sources

Figure 13 shows that in December 1998, the phosphorus flux from groundwater was 0.42 kg per day. This indicates that during the waterfowl wintering period, the phosphorus loading from groundwater may be less than that from bird droppings, which was 0.8 kg/d.

As shown in Figure 14, the daily internal phosphorus loading due to sediment release was dominant during summer but approximately equal to the daily loading from bird droppings during winter.

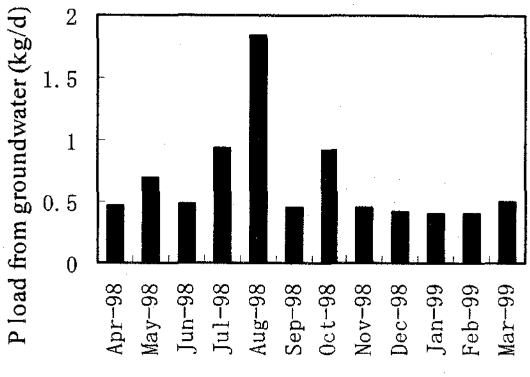


Figure 13 Monthly-averaged daily phosphorus loading to Sakata Lagoon from groundwater

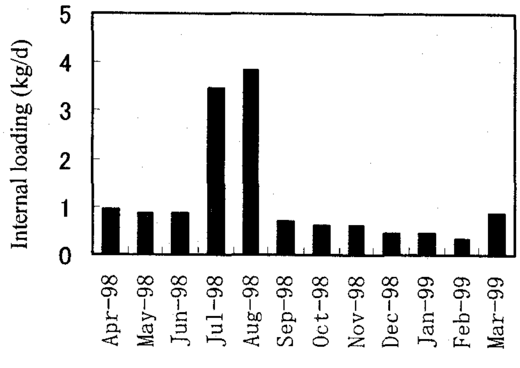


Figure 14 Monthly variation of daily phosphorus loading to Sakata Lagoon from sediment

5. Discussions

Lake managers may need to know how a water body responds to nutrient additions of different sources. To answer this question in Sakata Lagoon, the Vollenweider's model of nutrient loading-response was utilized. The formulation is given below (Vollenweider, 1976)

$$P = \frac{L}{H}\frac{T_w}{(1+\sqrt{T_w})} \quad (3)$$

where P=annual mean total phosphorus concentration (μg/l); L=annual phosphorus loading per unit surface area (g P/m^2/yr); T_w=residence time (yr); H=mean water depth (m).

Since the mean outflow from the lagoon was 15,170m^3/d according to the water budget survey of Niigata City, the water residence time was calculated to be approximately 30 days. Because migratory birds stayed in the lagoon for approximately two and half months, the annual nutrient load by migratory birds would be use-days×daily loading rate=60 kgP. Inserting the waterfowl-contributed load to Vollenweider's model resulted in a concentration of 0.009 mg/l. For comparison, we also calculated groundwater-induced and internal-load- induced total phosphorus concentrations in the lagoon waters using the Vollenweider's model. Putting those results into the Vollenweider's plot as shown in Figure 15, it can be seen clearly that the estimated waterfowl-generated nutrient level was on the verge of a transition from oligotrohic to eutrophic. Although loadings from internal release and groundwater dominated the waterfowl-generated loading on a yearly time scale, the contribution from waterfowl.was not negligible. More importantly, the lagoon was already in a highly eutrophic state and it would not function sustainably as an important habitat for migratory waterfowl unless all sources of nutrients were properly controlled.

Birds feeding in lakes may positively influence the waters by removing nutrients via food consumption. The transport of nutrients by waterbirds such as cormorant from the aquatic to the terrestrial environments has been studied from various angles (Hobara et al., 2005, Kameda et al., 2006). However, swans are herbivorous and they are often observed to forage on near-by paddy fields. The gleanings and the second ear of maize appear to be their favorite food (Mitchell, 1994; Niclas et al., 2002). Mallards are dabbling ducks. They feed anywhere that water is a foot or two deep, although they can reach for food in deeper water if necessary. They are primarily vegetarians and feed almost exclusively on plant matter. Their diet includes the roots of wild lilies, reeds and cattails, duckweed, and seeds from wild millet, rice, smartweed and other plants (Drilling et al., 2002). Since root decay of emergent aquatic plants under natural conditions is a lengthy process ranging from a few years to a few decades (Harmon et al., 1999; Nimal et al. 2005), removal of emergent plant roots by ducks may not be reflected in the yearly nutrient budget. And over-foraging of seeds by ducks may affect the growth of macrophytes. Mallards also forage on land and take advantage of human food sources, such as grain gleanings from crops (Lane et al., 1998). We observed that mallard flocks left Sakata Lagoon in the early morning and returned in the late afternoon to spend the night. It appears likely that they have foraged on land during the daytime. Although nutrient removal via waterfowl feeding is not considered in this study, it certainly deserves further attention.

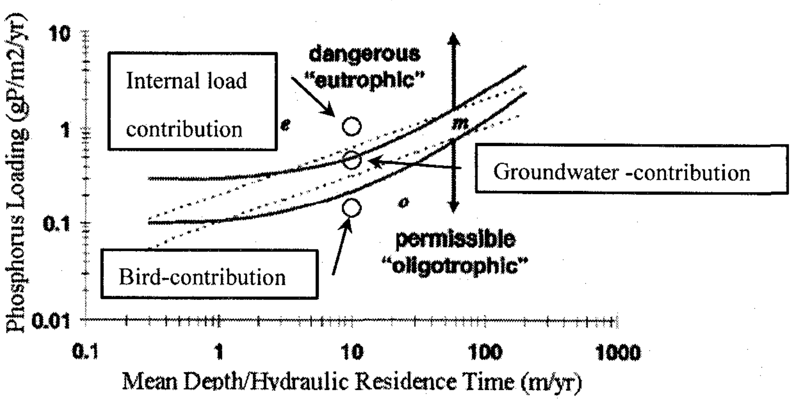


Figure 15 Responses of Sakata Lagoon to different phosphorus sources

6. Conclusions

The present study was a pioneering step in Japan toward quantitatively evaluating the impact of migratory waterfowl on the water quality of registered "Ramsar Site" water bodies. TP and TN loadings associated with wintering waterfowl flocks in the study site-Sakata Lagoon were estimated to be 0.8 kgP/d and 3.62 kgN/d, accounting for 80% and 25% of winter daily increases of lake TP and TN concentrations, respectively. Comparisons with other nutrient sources suggested that during winter, phosphorus daily loading by waterfowl exceeded that from groundwater and approximately equaled that from sediment release. For nitrogen, preliminary analysis in this paper served as a warning signal that bird droppings did not only contribute to lake nitrogen levels significantly, but they might also cause toxicity in the lagoon due to relatively high pH levels during winter. By making use of Vollenweider's model, responses of Sakata Lagoon to different phosphorus sources on a yearly time scale were shown. It indicated that although loadings from internal release and groundwater dominated the waterfowl-generated loading on a yearly time scale, the contribution from waterfowl was not negligible. More importantly, the lagoon was already in a highly eutrophic state and would fail to function sustainably as an important habitat for migratory waterfowl if actions were not taken promptly. Considering the fact that wetlands have been decreasing while the number of migratory waterfowl have been increasing in Japan, more study on sound wetlands management in relation to migratory waterfowl should be conducted in order for those registered "Ramsar Sites" in Japan to be able to support wintering waterfowl flocks sustainably.

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