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Estimation of nutrient input by a migratory bird, the Tundra Swan (*Cygnus columbianus*), to winter-flooded paddy fields

Hiroaki Somura [a,*], Tsugiyuki Masunaga [a], Yasushi Mori [b], Ikuo Takeda [a], Jun'ichiro Ide [c], Hirokazu Sato [a]

[a] Faculty of Life and Environmental Science, Shimane University, 1060 Nishikawatsu, Matsue, Shimane 690-8504, Japan
[b] Graduate School of Environmental and Life Science, Okayama University, 3-1-1 Tsushimanaka, Okayama 700-8530, Japan
[c] Institute of Decision Science for a Sustainable Society, Kyushu University, 6-10-1 Hakozaki Higashi-ku, Fukuoka 812-8581, Japan

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ABSTRACT

Thousands of Tundra Swans visit winter-flooded paddy fields in the study area, Yasugi city, Shimane Prefecture, Japan every year for overwintering from November to March. Since 2004, they have roosted in the paddy fields during the night and foraged in the paddy and surrounding fields during the day, coinciding with the time when farmers began using winter-flooded paddy fields. Before 2004, the swans visited the area for foraging during the day and roosted at nearby lakes, wetlands, and sandbars along rivers during the night. When the swans visited our target paddy fields, the water gradually became green and began to emit an ammonia-like odor. In this study, we investigated the changes in the water qualities of winter-flooded paddy fields and the influence of bird excrement on water quality in the paddy fields during winter, and then estimated the amounts of nitrogen (N) and phosphorus (P) provided by bird droppings to the paddy fields. The mean concentrations of N, P, suspended sediment, and total organic carbon were higher in the overwintering season than during the irrigation season. This trend was observed in both the first and second seasons of the study. The spatial distribution of electric conductivity (EC) measured using a GEM-2 broad-band electromagnetic sensor coincided with that of the matted sites of Tundra Swans in the paddy field, which indicated that the excrement of the swans affected the EC distribution. The total input amounts of N and P from the birds' excrement to the flooded paddy fields were estimated using a simple model that considered bird counts and probable nutrient content of feces, and the amounts were found to be equivalent to approximately 30% of those present in the standard fertilizers used for rice during the irrigation period. These results suggested that the excrement from the swans markedly influences the water qualities of winter-flooded paddy fields.

1. Introduction

Many herbivorous waterbird species frequently forage in terrestrial habitats but breed and rest in lakes and wetland areas (Hahn et al., 2008). Waterbirds adapt their foraging behavior and feed frequently in terrestrial agricultural habitats, particularly during winter (Gill, 1996; Mayes, 1991). Since they continue to roost in safe wetland sites, the increased numbers of waterbirds might presumably increase the nutrient input to these systems (Hahn et al., 2008). In other words, excrement from animals that feed outside but rest and/or breed in wetlands is a natural source of nitrogen (N) and phosphorus (P). At sites with abundant waterbirds, excrement can occasionally represent a major external nutrient source (Manny et al., 1994; Portnoy, 1990), particularly if the wetland is a favored roost for migratory birds (Post et al., 1998). Despite the obvious potential for herbivorous birds to mediate allochthonous nutrient input to freshwater bodies, few detailed studies have investigated the role of these birds in this process (Hahn et al., 2008).

Many migratory birds visit Japan every year for overwintering. Approximately 40,000 anatine waterbirds visit the brackish lakes Shinji and Nakaumi, designated as a Wetland of International Importance by the Ramsar Convention in November 2005 (MOE, 2012). Normally, these migratory birds remain in reservoirs, lakes, and wetlands around the area during winter, but some visit winter-flooded paddy fields and remain there continuously until March of the following year when they return to their place of

* Corresponding author. Tel.: +81 852 32 6552.
E-mail addresses: som-hiroaki@life.shimane-u.ac.jp, som.hiroaki@gmail.com (H. Somura).

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origin. The Tundra Swan, a waterbird species, spends a substantial portion of its annual cycle in migratory staging areas (Badzinski et al., 2011).

Paddy fields are the major land-use sources for agriculture in Japan. Approximately 54.3% of agricultural land is used for rice (MIC, 2012). Generally, rice is cultivated once a year during April or May to September or October, and paddy fields are not used after harvesting rice until the next season. However, in several paddy field areas, puddling procedures are performed after harvesting rice, and then water is stored in the paddy fields. These paddy fields accordingly come to resemble very shallow ponds during winter. This facilitates farming activities such as weeding in the next season and avoids the use of weedicides. These winter-flooded paddy fields are temporary artificial wetlands. The paddy fields are surrounded by earthen levees, and the water depth is maintained from approximately 0.05–0.1 m. These fields provide the Tundra Swans with a convenient site where they can rest without being threatened by predators, since they avoid earthen levees. Further, the swans can move easily and even walk in the shallow waters of the paddy fields, unlike in a deep lake. In addition, these sites can act as good foraging sites because the surrounding areas are agricultural lands that are used for cultivating crops such as rice and soybeans during the irrigation season.

Agriculture requires considerable energy input in the form of fertilizers, manure, irrigation water, pesticides, and weedicides. Tundra Swan excrement might provide an important source of N and P. Thus, evaluating the impact of Tundra Swan droppings in the paddy fields during winter is important for the efficient use of their nutrients during the irrigation season. Few studies have investigated the relationship between water quality in winter-flooded paddy fields and the behaviors of Tundra Swans. In this study, we initially investigated the changes in the water quality of winter-flooded paddy fields and the influence of bird excrement on the water quality in the paddy fields during winter. Subsequently, we estimated the amounts of N and P provided by bird droppings to the winter-flooded paddy fields.

2. Materials and methods

2.1. Study area

The study area is in Yasugi city, the southeastern portion of prefectural capital Matsue city, Shimane Prefecture, Japan (Fig. 1). In several paddy fields, since winter 2004, post-harvest chaff and residues of paddy rice have been plowed under the soil by using puddling procedures that are normally performed at the beginning of the cultivation period, and then the water is stored in the paddy fields during winter. Irrigation water is obtained from an adjacent river via a natural pressured pipeline system (Somura et al., 2009). Prior to 2004, Tundra Swans normally visited this area only during the day time for foraging activity and went to roost in nearby lakes, wetlands, and sandbars along rivers during the night. Although farmers did not expect that Tundra Swans would start roosting in their paddy fields during the night, the behavior of Tundra Swans changed after the introduction of winter-flooded paddy fields. The winter-flooded paddy fields were not created to encourage the visitations of migratory birds but to reduce the workload of removing weeds and the cost of weedicide application during the following season for producing rice. During our research, Tundra Swans visited the study area at the end of October in both 2006 and 2007, and puddling procedures were performed from the end of October to the beginning of November. The mean maximum and minimum air temperatures during November 2007–March 2008 at the nearby weather station were 11.4 °C and 3.4 °C, respectively. Further, snowfall was noted in the area during winter.

2.2. Methodology

Three paddy fields were selected as target sites in the study area. The area of each paddy field was approximately 10,000 m^2. Surface water stored in the paddy fields was sampled and analyzed almost once a week from November 23, 2006 to May 21, 2007 (first season), and once or twice a month from November 5, 2007 to March 17, 2008 (second season). We intended to choose the same paddy fields in both the seasons, but water was not introduced into two of the selected paddy fields at the beginning of the second season. Thus, two other paddy fields were selected from contiguous paddy fields. In the first season, the study focused on the quality of surface water in the target paddy fields. In the second season, in addition to water quality, the behavior of Tundra Swans in the target paddy fields was intensively assessed. Observations of bird behavior were complemented by measuring the change in the spatial distribution of electric conductivity (EC) in paddy field No. 3, which might have been affected by excrement accumulation on the bed of the field and concentration of dissolved substances in the water. The measurement was performed using a GEM-2 broad-band electromagnetic (EM) sensor (Aeroquest Sensortech; Geophex, USA), which is generally used for multiple-frequency EM sounding, at the following three times: before Tundra Swans roosted in the field, a month after flooding, and several months after flooding. Details of the methodology are as follows.

2.3. Water quality analysis

Water quality samples were collected using a cup and then immediately transported to our laboratory for analysis. In the laboratory, the water samples were filtered using glass fiber filters (Advantec GS-25) to separate the particles and dissolved substances. The filtered water was then stored in a refrigerator at 4 °C until analysis. The separated particles were dried and weighed to determine the concentration of suspended solids (SS). The total organic carbon (TOC) concentration was determined using a TOC analyzer (TOC-V_{CSN}; Shimadzu Co., Ltd. Kyoto, Japan). The ammonia (NH_4) concentration was determined using the indophenol method (Sagi, 1966). The nitrite (NO_2) concentration was determined using the naphthyl ethylene method in accordance with the Japanese Industrial Standard (JIS) K 0102 (Namiki, 1993). The nitrate (NO_3) concentration was determined using ion chromatography (PIA-1000; Shimadzu Co., Ltd. Kyoto, Japan). The total nitrogen (TN) concentration was determined using the ultraviolet spectrophotometry method with potassium peroxydisulfate (JIS K 0102). The phosphate (PO_4) concentration was determined using the molybdenum blue method (JIS K 0102). The total phosphorus (TP) concentration was determined using the molybdenum blue method with potassium peroxydisulfate (JIS K 0102).

2.4. Spatial distribution of electric conductivity in a paddy field

EC indicates the amount of soluble salts in the soil and dissolved materials in water. Thus, the spatial distribution of EC might show the accumulation trends of excrement on the bed of the field and of dissolved substances in the water, which would be attributed to the spatial roosting patterns and cumulative number/density of birds in the paddy field. Since high EC value in soil could affect the yield of crops (Breuning-Madsen et al., 2010), the information of spatial distribution might provide information regarding cultivation during the next season in the paddy fields.

The GEM-2 broad-band EM sensor has a small transmitter coil and receiver coil that are set in a ski-shaped board. When an EM field (primary field) is transmitted to the ground, an induced electric field is generated according to the eddy currents