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Quantification of whooper swan damage to lotus habitats using high-resolution acoustic imaging sonar in Lake Izunuma, Japan

Katsunori Mizuno[a,*], Kazuki Abukawa[a,1], Toru Kashima[a,1], Akira Asada[a,1], Yasufumi Fujimoto[b,2], Tetsuo Shimada[b,2]

[a] Institute of Industrial Science, The University of Tokyo, 4-6-1 Komaba, Meguro-ku, Tokyo 153-8505, Japan
[b] The Miyagi Prefectural Izunuma-Uchinuma Environmental Foundation, 17-2 Shikimi, Wakayanagi, Kurihara, Miyagi 989-5504, Japan

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ABSTRACT

Conventional survey methods (e.g., surface surveys using optical video cameras and divers) have been widely used to detect aquatic plants and estimate their densities. However, these methods are affected by the transparency of water and observational skills of the divers and usually require considerable amounts of time for high-resolution sampling. We developed a new measurement system that combines a high-resolution acoustic imaging sonar, i.e., a Dual-frequency IDentification SONar (DIDSON) with a 1° concentrator lens, motion sensors, and GPS (global positioning system) receivers to quantify the underwater status and topography of a lake bottom effectively without the transparency of the water affecting the results. High-resolution spatial acoustic imaging was used for 3D visualization of the underwater status and bottom topography of a lake, and the numbers and depths of lotuses and bottom holes were estimated using the image processing program developed for this study. Our study revealed one specific aspect of the interaction between whooper swans foraging and the density of lotus (*Nelumbo nucifera* Gaertn.). The threshold water depth (approximately 1.3 m) between high- and low-density areas was related to the body length of whooper swans.

1. Introduction

Studies of aquatic plant–herbivore interactions have reported the impacts of herbivory on the community structure and prevalence of aquatic plants (Augustine and McNaughton, 1998; Nolet et al., 2002; Hanley et al., 2007; Sandsten and Klaassen, 2008; Hidding et al., 2012). Conventional survey methods (e.g., surface surveys using optical video cameras and divers) have been widely used to detect aquatic plants and estimate their densities (Dromgoole and Brown, 1976; Norris et al., 1997). For example, Sandsten and Klaassen (2008) estimated the vegetation and water depth by direct measurements at 173 points, which involved throwing a 0.5 m × 0.5 m metal frame into the water and diving to look for plants. However, such methods can be patchy for large stands of aquatic plants, and quantification requires high-resolution sampling. Furthermore, classical sampling is always affected by the transparency of the water and the observational skills of the divers and usually requires a considerable amount of time.

To overcome these disadvantages, two types of remote sensing methods are used widely for mapping aquatic plants: optical and acoustic remote sensing methods. Satellite remote sensing has been used for mapping and detecting large changes in seagrass distribution (Zainal et al., 1993). Similarly, Dekker et al. (2005) analyzed satellite images of Wallis Lake, detected significant changes in seagrass, and demonstrated the changes over a wide area with high efficiency. However, the optical method is affected by the clarity of the water and cannot always be used successfully to map aquatic plants, especially in eutrophied lakes or ponds. Acoustic systems, such as side-scan sonar (Pasqualini et al., 1999), echosounders (Sabol et al., 2002; Han et al., 2007; Lefebvre et al., 2009), and multibeam sonar (Komatsu et al., 2003; Asada et al., 2005; Abukawa et al., 2013), have been used without interference of transparency. In shallow areas, sonar systems with high frequencies, in the MHz range, have been used to survey aquatic plants because sonar allows the acquisition of high-resolution spatial data, which helps in estimating the abundance of aquatic plants (Lefebvre et al., 2009).

In recent years, the use of Dual-frequency IDentification SONar (DIDSON), a form of high-resolution imaging sonar, has allowed the production of near-video quality images by simultaneously transmitting and receiving multiple acoustic beams (Belcher et al.,

* Corresponding author. Tel.: +81 3 5452 6188; fax: +81 3 5452 6189.
E-mail address: kmizuno@iis.u-tokyo.ac.jp (K. Mizuno).
[1] Tel.: +81 3 5452 6188; fax: +81 3 5452 6189.
[2] Tel.: +81 228 33 2216; fax: +81 228 33 2217.

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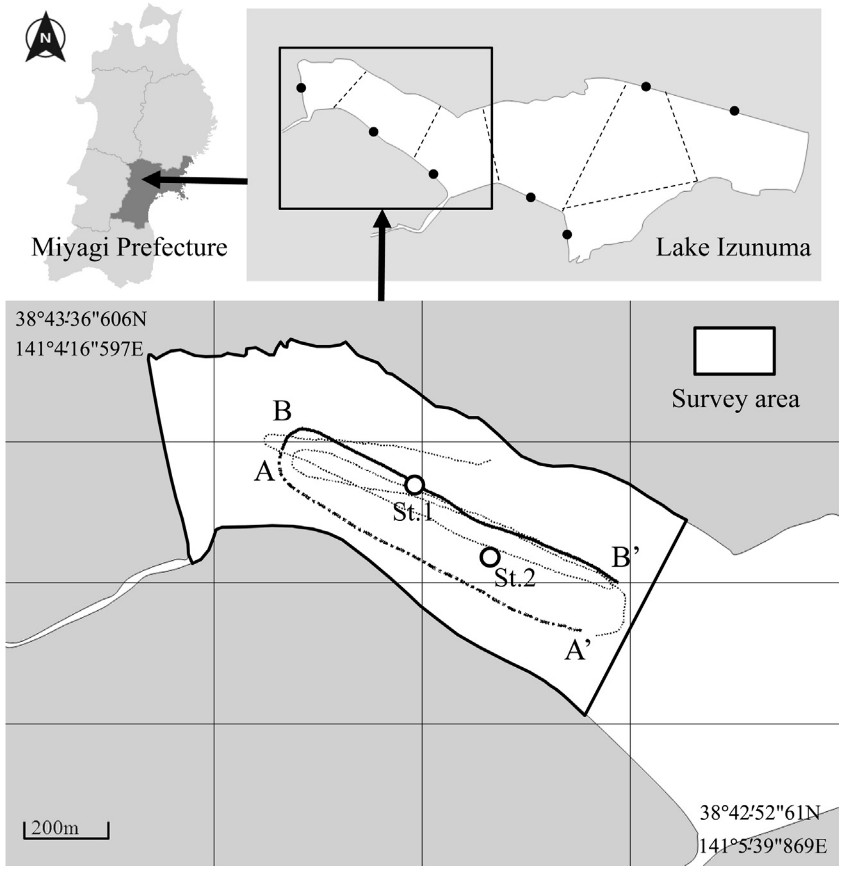

Fig. 1. Map of Lake Izunuma in the Miyagi prefecture showing the study site. On the map at right top, (●) is an observation point; (- - -) is the boundary of fixed-point censuses. The acoustic survey was performed within the two left census areas enclosed by the bold line on the bottom map. All traces obtained between 12:19 and 13:50 on 19 June 2012 are shown on the map as lines.

2002). DIDSON is used by many fishery researchers and scientists for a wide range of purposes, e.g., observation of fish behavior (Moursund et al., 2003), size detection (Boswell et al., 2008), counting (Holmes et al., 2006), abundance estimation during trawling (Handegard and Williams, 2008), and classification of fish shapes (Burwen et al., 2007). Chunhui et al. (2013) were the first to apply DIDSON to an aquatic plant survey in a shallow lake. They classified three aquatic plants, i.e., *Myriophyllum spicatum*, *Chara globularis*, and *Elodea nuttallii*, using high-resolution acoustic images captured from Lake Yunoko, Japan. However, the results were focused on the plants themselves; the influences of other informative environmental factors, such as topography and sediment features at the lake bottom, on plant habitat were not been examined. High-resolution acoustic monitoring is non-destructive and can measure the topography of a lake bottom with high accuracy.

The aims of this study were to develop an efficient method for investigating the status of lakes using spatial acoustic images of aquatic plants and bottom topography and to quantify swan damage to lotus habitats using high-resolution spatial resolution acoustic imaging sonar at 1.8 MHz.

2. Materials and methods

2.1. Survey site

The survey area was the left part of Lake Izunuma (38°43′ N, 141°04′ E) (Fig. 1). The lake was registered as a wetland under the Ramsar Convention in 1985, and it is located in northeastern Japan. This lake is eutrophic and shallow (the maximum depth is 1.6 m; the surface area is 3.69 km^2) (Shitara, 1992). The average COD (chemical oxygen demand) in 2011 was 8.8 mg/L, which was the second worst among 188 Japanese lakes (Ministry of the Environment, 2012). A large portion of the lake has been dominated by lotus (*Nelumbo nucifera* Gaertn.), and the area of the lake covered by lotus has increased rapidly since 2006, according to information obtained from aerial photography: 23% in 2006 and 44% in 2008 (The Miyagi Prefectural Izunuma-Uchinuma Environmental Foundation, 2010). Lake Izunuma-Uchinuma is also designated as a National Bird and Animal Protection Region, and it is one of the most famous wintering grounds for swans and geese in Japan (Shimada, 2000, 2002). Visual censuses of birds were carried out 3–6 times per month during the winter of 2011–2012. The visual census procedure was the same as that described in previous reports (Shimada, 2000) and involved the use of 10 × 35 binoculars, 30 × 67 telescopes, and hand-counters. At Lake Izunuma, the bird censuses were conducted at 7 fixed observation points to count the number of swans on the open water (Fig. 1). Then, the whole area of the bird census was divided into 7 areas by the boundaries of the fixed-point censuses. The acoustic survey was performed during summer within the 2 left areas, where a total of 7430 swans were observed during the winter of 2011–2012 (Fig. 1 and Table 1). Additionally, foraging behavior of swans was observed often at the survey areas during the visual bird census: 370 times in December 2011, 241 times in January 2012, 251 times in February 2012, and 5 times in March 2012. During the spring of 2012, lotus was abundant in the lake, but density differed between the left (low) and right (high) parts within the surveyed areas, according to the results of aerial photography.