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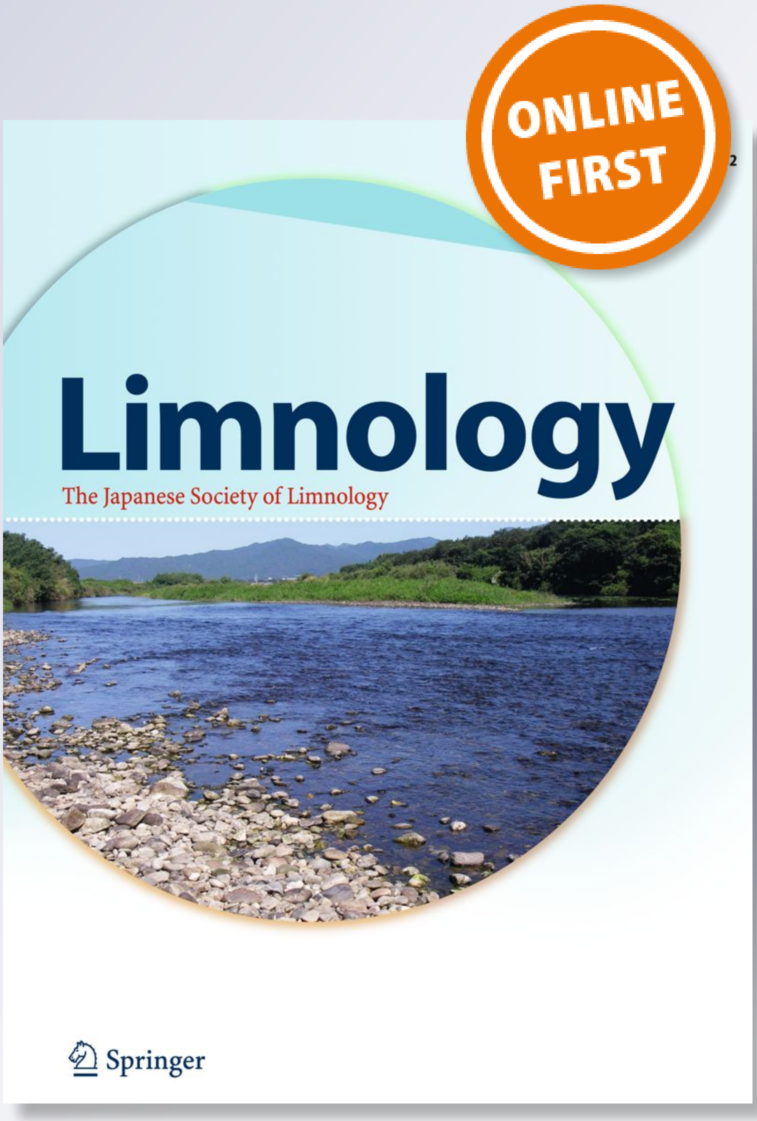

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RESEARCH PAPER

Assessing the biomass and distribution of submerged aquatic vegetation using multibeam echo sounding in Lake Towada, Japan

**Kazuki Abukawa · Masumi Yamamuro ·
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Abstract Here we report on an advanced survey system that combines multibeam echo sounding with underwater photography, which was used to collect accurate data on the distribution and abundance of submerged aquatic vegetation (SAV) in Lake Towada. The use of this system enabled us to visualize the cover, height, and biomass of the SAV over the lake bottom, as well as to distinguish between different components of the SAV such as vascular and algal plants. The spatial distributions of these major components of the SAV varied as a function of the depth gradient. The vascular component was mostly represented by *Potamogeton* species, which accounted for around one-third of the standing mass of SAV, whilst more than half of the SAV was algal (charophytes). This abundance of charophytes may well be responsible for the high water quality and transparency of Lake Towada.

Keywords Submerged aquatic vegetation · Multibeam echo sounder · Distribution · Biomass · Charophyte

Introduction

Human activities such as lakefront construction, as well as the effects of human activities (such as eutrophication), threaten the existence of charophytes in many lakes worldwide, especially in developed countries. For example, in Japan, the proportion of endangered tracheophyte species that are on the Red List reached 43 % in 2007; among these, 62 out of the 78 charophyte species are in danger of extinction due to carp grazing and herbicide overuse (Watanabe et al. 2005). Measures to conserve submerged aquatic vegetation (SAV) require in situ studies to clarify the distribution and functions of this important but poorly understood type of vegetation (Vis et al. 2005).

Special equipment and skills are needed to sample SAV, but existing methods of data collection lack accuracy. These methods can be divided into three categories: (1) direct sampling, (2) off-water remote sensing, and (3) on-water sensing. Direct sampling includes the use of an extraction device and observations by divers from shore and/or a boat. Sampling using an extraction device permits species identification, but cannot provide accurate data on where the plant is growing underwater. Observations by divers provide more accurate distribution data, but are only practicable in a small region. By contrast, off-water remote sensing uses optical information obtained from aerial and satellite imagery. The resulting passive imagery (photographs and digital images, the quality of which depends on solar illumination) is interpreted subjectively by a researcher or digitally with the aid of computers. Satellite photography allows fast surveying over wide areas, but it cannot sense deeply submerged SAV and cannot be used for small lakes.

On-water remote techniques may also include SAV observations with an underwater camera (used simultaneously

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K. Abukawa (✉) · A. Asada · C. Xu
Institute of Industrial Science, The University of Tokyo,
4-6-1 Komaba, Meguro-ku, Tokyo 153-8505, Japan
e-mail: akajika@iis.u-tokyo.ac.jp

M. Yamamuro · Z. Kikvidze
Department of Natural Environmental Studies,
Graduate School of Frontier Sciences, The University of Tokyo,
5-1-5 Kashiwanoha, Kashiwa, Chiba 277-8563, Japan
e-mail: yamamuro@k.u-tokyo.ac.jp

K. Sugimoto
Windy Network Inc., 6-4-25 Magarikane, Suruga-ku,
Shizuoka, Shizuoka 422-8006, Japan

with or after sensing). Echo sounding can measure the area and height of vegetation, but it requires the investment of a great deal of time to cover a representative lake area.

Reflecting the growing interest in seagrass beds from the perspective of environmental protection and use by fisheries, several on-water remote techniques have been developed recently; these techniques allow seagrass bed coverage to be monitored by a remotely operated vehicle (ROV) equipped with a digital camera and quadrat (Yamamuro et al. 2003) and an echo sounder (Lefebvre et al. 2009). Three-dimensional measurements and visualization of the seagrass and seaweed above seafloor using a multibeam echo sounder can even the heights of beds to be evaluated (Asada et al. 2005; Komatsu et al. 2003).

Here we report on an advanced survey system that combines multibeam echo sounding with underwater photography, which was used to collect accurate data on the distribution and abundance of SAV in a lake.

Study area

Lake Towada is located at the border of the Aomori and Akita prefectures, northern Honshu, Japan (40°24′–40°30′N, 140°49′–140°58′E, Fig. 1). The lake is situated at an elevation of 400 m, has a surface area of 61.0 km^2, 46 km of shoreline, and its maximum and mean depths are, respectively, 326.8 and 71.0 m. The lake water is highly transparent and harbors well-developed SAV (National Astronomical Observatory of Japan 2010). This water has low COD, low total phosphorus, and low total nitrogen, and is highly transparent—it is the clearest water of any lake in Japan (Aomori Prefecture 2010). However, vegetated areas are limited to the east and west littorals due to the very steep topography of this lake. Typical SAV species include *Chara globularis*, *Nitella flexilis*, *Ranunculus nipponicus*, *Hydrilla verticillata*, *Myriophyllum spicatum*, *Potamogeton compressus*, *Potamogeton gramineus*, *Potamogeton maackianus*, *Potamogeton pectinatus*, and *Potamogeton perfoliatus*.

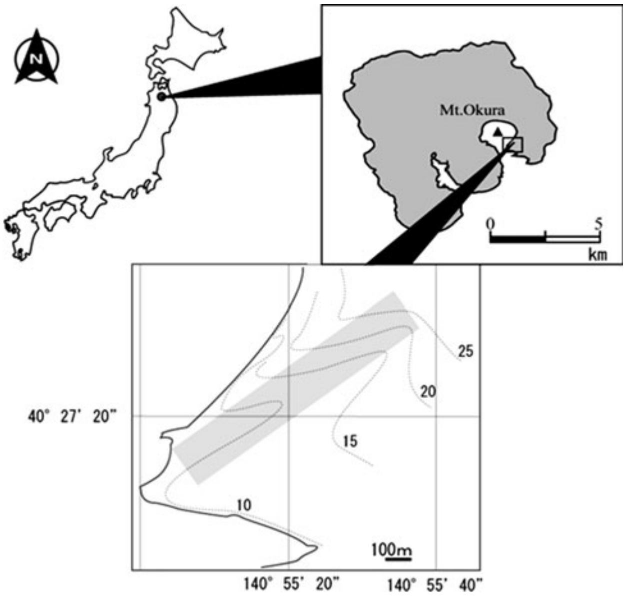

Fig. 1 Lake Towada: its location and landscape. Our survey linearly transected the cove near Mt. Okura in the eastern part of the lake. The *gray zone* shows the survey area. The survey area was located at 40°27′23″N, 140°55′20″E, and the range of depths was 3–20 m

Our survey linearly transected the cove near Mt. Okura in the eastern part of the lake (center of transect latitude/longitude; 40°27′23″N, 140°55′20″E, Fig. 1), which is characterized by a gentle bottom slope with a depth range of 3–20 m. Sediment types were rock, sand, and mud (depth range ca. 3–10 m) or just mud (deeper than ca. 10 m). The survey was performed in August 2010.

Survey system

Our system acquires data on bathymetry, lake bottom topography, and the height of SAV using a multibeam echo sounder. It consists of a multibeam sonar device (Sonic2024, R2sonic Inc.) and a POS/MV connected to RTK-GPS as well as an inertial motion sensor (POS MV 320, Applanix Corporation, Fig. 2). The Sonic2024 has 256 beams and the operating frequency of the multibeam sonar is 400 kHz. Multibeam bathymetry data as well as position (longitude and latitude) and elevation data (heave, roll, and pitch) were collected using the HYPACK software package. Traveling speed is 1.5 m/s during a round-trip transect. We subsequently photographed plants with an

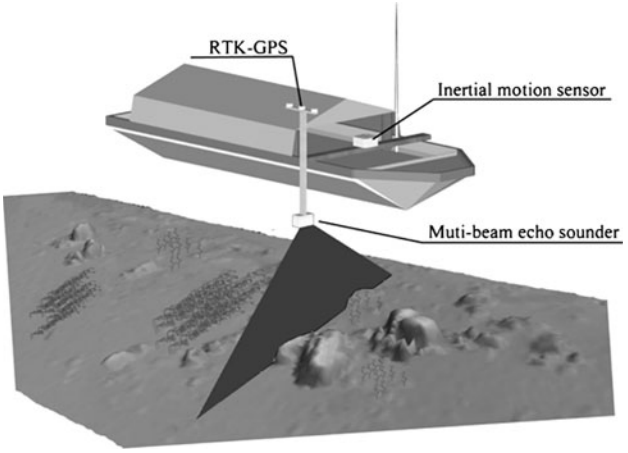

Fig. 2 Schematic representation of the multibeam sonar survey system

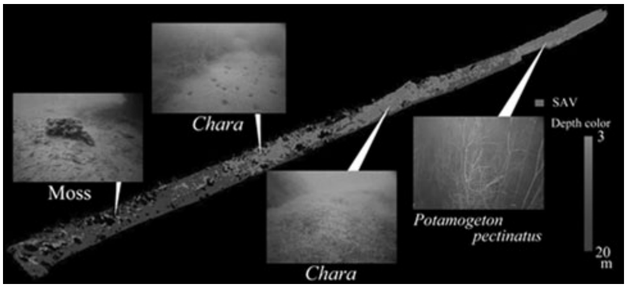

Fig. 3 The map produced by processing the sonar survey data

underwater camera and used a direct extraction device to sample the vegetation and identify species.

Data processing

The initial step in the data analysis was to process the sonar signals from the echo sounder. The raw data from HYPACK was fed to the GIS software HIPS&SHIPS (CARIS Inc.), which was programmed to uncouple the bathymetric data from the SAV data and produce two data sets: one for the lake bottom and another for the water column, which included lake bottom data. The bathymetric data were first corrected using the sound velocity profile and tide data, and then merged with the vessel data. Then the noise and SAV data were deleted to produce the lake bottom data. In parallel, noise was deleted from the bathymetric data to produce water column (SAV) data that included the bottom data.

The next step was to construct a topographic map with the SAV for the survey transect. The bottom of the surveyed area was divided into a grid of 0.25 m × 0.25 m cells and the average depth was calculated. The topography was color-coded according to depth (dark gray to white), whilst a green color was assigned to the SAV. The program not only visualized the distribution of the SAV; it also calculated its coverage and volume using the bottom grid data and water column (SAV) data. The same size grid was used for the SAV and the height of the vegetation was added (minimum height 0.1 m). In the next step, the coverage and volume of SAV was calculated and mapped (Fig. 3). The coverage and volume data were then used together with the data from photography and direct extraction sampling to describe the SAV structure and distribution. In particular, to validate the height and volume values for the SAV obtained from the multibeam echo sounder, we compared 4 m × 4 m quadrat data at two points. The quadrat was divided into a 25 cm × 25 cm grid and the error in the average height of the vegetation was calculated.

Results and discussion

The depth distribution of the surveyed area shows that the rock at the lake bottom forms a depression with an increasingly steep slope, such that depths from 12 to 20 m accounted for more than 50 % of the recorded depth values. Overall, the sampled area totaled 28,476 m^2, 6.8 % of which (1948 m^2) was vegetated (total volume 1324 m^3). However, the vegetated area and, especially, the abundance of vegetation were not uniformly distributed—two bands were seen, with the first corresponding to depths of 3–6 m, and the second and broader one corresponding to mostly 8–12 m depths. Different plants dominated these two bands of vegetation.

Among the three vegetation components that could be distinguished using the underwater camera (*Chara*, *Potamogeton*, and bryophytes), *Chara* was the most abundant, with a total of 732 m^3 at depths of 8–12 m, which is more than half of the total vegetation cover (53 %) and volume (54 %). *Chara* started to appear at depths of >6 m, and was most abundant at depths of 8–12 m; *Chara* then gradually declined with increasing depth, and could not be seen deeper than 18 m, where it was replaced by bryophyte vegetation. By contrast, *Potamogeton* grew mainly at shallower depths (4–6 m), and represented 30 % of the total vegetation volume measured.

Validation showed that the frequent appearance error of *Chara* at a depth of 5 m was 2–4 mm. Although the frequent appearance error of *Potamogeton* was 0–0.2 m and 0.2–0.4 m, some grids showed differences of between 0.8 and 1 m. The mean error for *Potamogeton* was 0.45 m. This error in height estimation was due to differences in the statures of two species relative to the position of the multibeam echo sounder. *Potamogeton* is tall, with long and narrow upright shoots, so calculations produced proportionally higher error values. Conversely, *Chara* always creep across and densely cover the lake bottom, so the error for *Chara* was much less than that for *Potamogeton*. Similarly, as the volume of SAV is calculated from the mean height of the SAV in the grid-to-grid area, the estimates for *Potamogeton* produced larger errors than those for *Chara*. The development of an improved calculation algorithm that accounts for the plant architecture is needed to permit better estimation of the volume of SAV.

Based on the results described above, our advanced survey system using multibeam sonar appears to be an effective tool for mapping the structure, height, and coverage of SAV in a lake, and quantifying its abundance (volume in the water column). To our knowledge, this is the first work to accurately determine and visualize the distribution of SAV across a wide area rather than just along a transect. The multibeam sonar data can also be used to derive volume data for plant canopies, which would prove useful for the management and long-term monitoring of lakes and studies of SAV.

This study documented a stratified SAV structure in which *Potamogeton* occupies shallower areas whilst charophytes grow at greater depths. *Potamegeton* can be a better competitor for light, whilst *Chara* can survive at lower bicarbonate concentrations (Van den Berg et al. 1998; Van den Berg 1999). As a result, charophytes concentrate most of their biomass close to the sediment surface, whereas *Potamogeton* can form canopies just below the surface of the water. *Potamogeton* probably competitively excludes charophytes from shallow depths where light conditions are more favorable (Scheffer and van Nes 2007). Consequently, because limited light penetration at greater depths prevents vascular plants from colonizing the lake bottom, dark-tolerant charophytes can establish in and dominate these deeper sites.

This study was able to distinguish between different components of the SAV, such as vascular and algal plants. The vascular component was mostly represented by *Potamogeton* species, which accounted for around one-third of the standing mass of SAV, whilst more than half of the SAV was algal (charophyte species). This abundance of charophytes may well be responsible for the high water quality and transparency of Lake Towada. Indeed, charophytes purify water through a process of phosphorus calcification, forming insoluble calcium phosphates (Siong and Asaeda 2006). When phosphorus coprecipitates during charophyte calcification, the underwater phosphorus density decreases and the transparency of the lake is maintained (Hilt et al. 2006). In addition, charophytes remove heavy metals from the water, including arsenic and cadmium ions (Siong and Asaeda 2009).

We can therefore conclude that the multibeam sonar system used in this study is highly accurate and effective. This method can also be combined with other approaches to achieve even higher accuracy at points of special interest—for example, a diver or a remotely operated vehicle can re-sample selected focal points after surveying a wider area with a side-scan sonar and multibeam echo sounder. The current version of this system employs narrowly directed beams to scan the lake bottom, and has to measure all scattered sonic waves. The precision and effectiveness of SAV mapping would be increased manyfold if a multibeam echo sounder with a wider beam (up to 180°) were to be developed.

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