

## Accumulation and distribution of cesium in *Egeria densa*, a submerged plant

Radionuclides were discharged into the environment in the northeast region of Japan after the destruction of the Fukushima Daiichi Nuclear Power Station, located approximately 250 km north of Tokyo, in March 2011. The radionuclides fell on the land and were dispersed by rainwater and mountain streams to rivers, lakes, and ponds. Radioactive cesium (134Cs and 137Cs) is a major fission product and plays a crucial role in both external and internal doses, because of the emission of beta and gamma radiation, the long half-lives (134Cs: 2.06 years, <sup>137</sup>Cs: 30.2 years), and its rapid incorporation into biological systems [1]. The development of techniques for the removal of radioactive Cs requires knowledge of the mobility of Cs in the environment. Several reports have shown that the fate of <sup>134</sup>Cs and <sup>137</sup>Cs derived from the nuclear accident fallout and associated radiological hazards are strongly dependent on their mobility in the surface soils.

Plant uptake is a major pathway for the migration of radiocesium from the soil to the human diet. To predict the movement of radionuclides and to remove them from the northeastern area of Japan, the radioactivities of terrestrial plants have been monitored and reported in several articles. The released radionuclides have also probably been incorporated into aquatic ecosystems; however, there is little information about the contamination of freshwater ecosystems.

In this work, we focused on the bioaccumulation of Cs in a freshly submerged vascular plant, *Egeria densa* (Brazilian waterweed, Hydrocharitaceae), to investigate the behavior of Cs in fresh aquatic ecosystem. We collected *E. densa* plants, waters, and sediments that are contaminated by radioactive fallout in Fukushima Prefecture in September 2012 (Fig. 1(a)). The activities of <sup>134</sup>Cs, <sup>137</sup>Cs, and <sup>40</sup>K were measured using a germanium semiconductor detector (Fig. 1(b)).

Environmental radioactive Cs concentration varied among the sampling points. The highest total radiocesium (<sup>134</sup>Cs and <sup>137</sup>Cs) activity was 123 Bq·kg<sup>-1</sup> from fresh plants sampled in Minamisoma. <sup>40</sup>K is a natural isotope whose percentage of the total potassium content found in nature has been estimated to be 0.0117%, and whose concentration in farming soils ranges from 150 to 500 Bq·kg<sup>-1</sup> in Japan. Radiocesium was accumulated mainly in sediments and had concentrations of 1800 (Koori), 124 (Nishiyama), 1300 (Nakamura), and 20 900 (Minamisoma) Bq·kg<sup>-1</sup>, which partially correlated with the air dose rates.

To discuss the uptake mechanism of Cs, stable <sup>133</sup>Cs was applied separately to shoots and roots in a



Fig. 1. Sampling sites in Fukushima Prefecture. (a) *E. densa* plant, sediment, and water samples were collected from Koori (1) in Date-gun, Nishiyama (2) and Nakamura (3) in Soma-shi, and in Minamisoma (4), and the sampling sites are shown on the distribution map of the total dose rate of <sup>134</sup>Cs and <sup>137</sup>Cs obtained by airborne monitoring in June 2012 (Extension Site of the Distribution Map of Radiation Dose, Digital Japan, *http://ramap.jmc.or.jp/map/eng/*). (b) Spectra for *E. densa* shoots sampled in Minamisoma. The counting time was 20000 s and <sup>134</sup>Cs, <sup>137</sup>Cs, and <sup>40</sup>K were detected.

two-compartment bath (Fig. 2(a), [2]). Leaves around the stem-root joint were removed. The joint was wrapped with a plastic paraffin film and inserted into a slit between the two chambers. The slit was carefully sealed with a silicone sealant to avoid leaking of the media. The contents of Cs were determined by furnace atomic absorption spectrometry. The results showed that the environmental Cs transferred to both the shoots and roots of plants (Figs. 2(b-d)).

To analyze the detailed localization of Cs in plants, synchrotron radiation-based micro X-ray fluorescence (SR- $\mu$ -XRF) analysis was performed for plants cultivated in a hydroponic medium containing <sup>133</sup>Cs [3]. The newly developed small plants were excised from the node of a mother plant and rinsed with water

(Fig. 3(a)). Then the small plants were pretreated in a plastic bucket containing 3 L of medium for 24 h and transferred to plastic containers containing 500 mL of Gaudet's medium and 20 µM CsCl for 72 h. Because the plants' leaves contain a single longitudinal vascular bundle and the blades consist of only two layers of cells, the elemental distribution of a leaf segment was shown without preparation of sections of the tissue. Highresolution imaging was then performed at BL37XU to observe the subcellular distribution of Cs. Strong Cs signals were detected in the cell wall and in the apoplastic regions (Fig. 3(b)). The distribution mobility of Cs appears to be similar to that of K as well as divalent metals, such as Ca, Mn, Fe, and Zn, indicating the nonspecific absorption of metals by the cell wall or apoplastic regions. The apoplastic detoxification of



Fig. 2. Endogenous Cs concentrations ( $mg \cdot kg^{-1}$  DW) in the shoots and roots of *E. densa*. (a) The plants were incubated in a small two-compartment bath. (b) Both shoots and roots, (c) shoots, and (d) roots were treated with 2, 20, and 200  $\mu$ M CsCl for 24 h. Values are means  $\pm$ SD (n = 3). Asterisks indicate a statistically significant difference: \*P < 0.01. Statistical analysis was performed by an unpaired Student's t-test.

Cd was previously observed in the pith of the young stems of a willow [4]. We consider that *E. densa* plays an important role in the deposition of radioactive Cs in fresh water and that it will be useful for the removal of radiocesium from water columns.



Fig .3.  $\mu$ -XRF imaging of the leaf of *E. densa* treated with CsCl. (a) The leaf was set over a  $4 \times 4 \text{ cm}^2$  acrylic plate with a 1.0-cm-diameter hole and covered with a Mylar film. (b) High-resolution images of the area of the leaf in the red square. Two-dimensional distributions of K, Cs, Zn, Fe, Ca, and Mn are shown. The XRF signal intensity is shown as a color scale. Beam energy: 10 keV. Step size: 2.0  $\mu$ m. Exposure time: 0.5 s per point.

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## References

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