Water-Holding Capacity of a Floating Peat Mat Determines the Survival and Growth of *Menyanthes trifoliata* L. (Bog Bean) in an Oligotrophic Lake

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Menyanthes trifoliata **is a threatened and endangered species in Korea and USA. To assess the important ecological characteristics for its conservation and restoration, we measured the level of soluble reactive phosphorus (SRP) in the water, total N and C contents in the plants, and the water-holding capacity of the surrounding floating peat mat. These factors, which limit the success of aquatic macrophytes, were examined for their effects on the growth of this species. Leaflet areas and petiole lengths ranged from 6.1 cm^2 and 12.4 cm, respectively, at a water depth of 5 cm, to 22.7 cm^2 and 33.0 cm, respectively, at 40 cm. The peat mat was able to retain water at a depth of 5 to 45 cm. SRPs ranged from 10 to 46 ppb, while total C and N contents were between 0.62% (petiole) and 2.76% (leaf), and between 39.7% (petiole) and 43.8% (stem), respectively. The water-holding level was not correlated with SRP, and neither phosphorus nor nitrogen content affected plant growth. However, the capacity of the floating mat to hold water as the depth subsided was positively related to growth. This suggests that such mats are good tools for restoring populations of *M. trifoliata* when materials with high water-holding capacities are used.**

Keywords: conservation, floating peat mat, *Menyanthes trifoliata*, restoration, water depth

The distribution of aquatic macrophytes is restricted by environmental factors such as geography, physical and chemical features of the water, soil texture, cations, and available nutrients, e.g., nitrogen and phosphorus (Mitsch and Gosselink, 2000; Lee et al., 2005). The most influential variables are hydrology, alkalinity, pH, and nutrient composition, as they relate to elevation (Vestergaard and Sand-Jensen, 2000; Heegaard et al., 2001; Magee and Kentula, 2005). Poor fen sub-community types are typically distributed along a primary environmental gradient of surface water height, and depend on the depth of organic matter and the bare substrate (Southall et al., 2003). Water-holding capacity is another important factor that determines this distribution and the performance of aquatic plants on floating mats (Howes et al., 1986; Magee and Kentula, 2005).

Menyanthes trifoliata is found along the shallow margins of oligotrophic lakes or in the floating peat mats of bogs (USDA NRCS, 2005). Increased air pollution, however, has changed these oligotrophic conditions to those that are eutrophic, consequently reducing its available habitat (Goldman and Byron, 1986). This species is designated as threatened in Iowa, North Carolina, and Ohio (all in the US) as well as in Korea, and is considered endangered in Maryland (US). To conserve or restore its populations, we must know its ecological and genetic characteristics. Because few studies have been conducted (Haraguchi, 1996, 2004), the objective of our research was to determine how water-holding capacity affects the growth of *M. trifoliata* on floating peat mats.

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MATERIALS AND METHODS

Description of *M. trifoliata*

M. trifoliata is a rhizomatous emergent aquatic perennial that typically grows in shallow water along pond/lake margins, and on floating peat mats in bogs. In the wild, plants often form large colonies. This species, native to Europe, North America, and Asia, has a distribution range in Korea that extends north of Daekwanryung (Lee, 1999). Its flower stalks and leaves rise well above the water surface from thick creeping rhizomes that spread indefinitely. The trifoliate leaves have three elliptic leaflets (up to 10 cm long) on petioles (10 to 25 cm long). In May and June, starry, 5-petaled, hairy white flowers bloom in terminal racemes atop stems as tall as 30 cm. This plant is classified as an obligate wetland indicator (USDA NRCS, 2005). Its roots and shoots provide a route for high conductance of methane moving between the peat and the atmosphere (Daulat and Clymo, 1998; Macdonald et al., 1998).

Study Site

The study site is located in the Sierra Nevada mountains of east-central California, USA (38°47′N, 119° 57′W, 2333 m a.s.l.; Fig. 1). There, Grass Lake is a bog dominated by moss-forming, floating peat mats. The dominant species are *Sphagnum squarrosum*, *Menyanthes trifoliata*, *Carex limosa*, *Eriophyllum gracile*, and *C. rostrata*. Most of this area comprises 11 plant associations, as well as moss and Sphagnum associations (Burke, 1987). Representative associations include Drepanoclado-Utricularietum (Brown Moss-Bladderwort), Mimulo-Caricetum limosae (Monkeyflower-Shoresedge), Caricetum simulato-rostratate (Long and Short-beaked Sedges), and Caricetum nebraskensis (Nebraska Sedge). With a northern aspect, this 7.7-ha bog is surrounded by mid-boreal-type coniferous forests on a watershed of 240 ha.

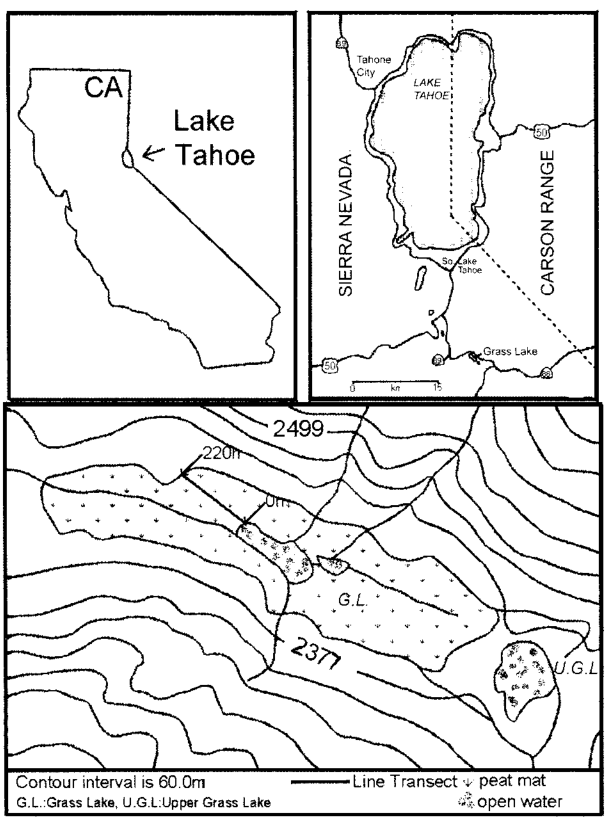

Figure 1. Study site and location of line transect.

Methods

Shoots of *M. trifoliata* plus water samples were collected in September along a line transect, when foliage density is the second highest (Haraguchi, 2004). A 220-m-long transect was set from the open water to the northwest edge of Grass Lake. *M. trifoliata* is distributed discontinuously there, and 100 leaves total were collected at 5 locations. The level or depth to which water could be retained by the peat was determined by having a 70-kg person stand on the floating mat and measuring from his feet to the top of the water. For plant measurements, the shoots were divided into their leaflet, petiole, and stem (rhizome) portions. Leaflet areas were determined with a portable area meter (Model LI-3000A; LI-COR, USA); petioles were measured with a ruler. For each location, 20 leaves were sampled and more than 45 leaflets were analyzed for area. Afterward, the samples were dried at 80°C and ground to a powder with a mill. Total carbon and nitrogen contents were determined on a Carlo-Erba Series 5000 CHN-S Analyzer, Italy. The soluble reactive phosphorus (SRP) content in the water was determined colorimetrically (Hunter et al., 1993).

RESULTS AND DISCUSSION

Emergent aquatic macrophytes, such as *M. trifoliata*, play a role in sequestering phosphorus by rhizosphere oxidation (Moore et al., 1994). In boreal rich-fen communities of low productivity, phosphorus generally limits plant growth (Oien, 2004). However, we found no relationship between SRP and water depth (Fig. 2), and *M. trifoliata* grew better in deep water (45 cm) than in shallow places (~10 cm) even though SRP in the deeper regions (at 180 m along the line transect) was as low as 10 ppb (Fig. 2).

Leaflet areas and petiole lengths ranged from 6.1 cm^2 and 12.4 cm at a water depth of 5 cm, to 22.7 cm^2 and 33.0 at 40 cm. Relationships were highly and positively correlated ($p < 0.01$) between area and length and the depth of the water. Large communities formed on both edges of the floating peat mat while plants were also scattered in other, shallow areas. Water depth rather than phosphorus content proved to be an important limiting factor for plant growth (Fig. 2, 3). Leaflet area was positively correlated with petiole length ($p < 0.05$; Fig. 4), and leaves tended to be larger and to have longer petioles when growing on a floating mat that held relatively more water.

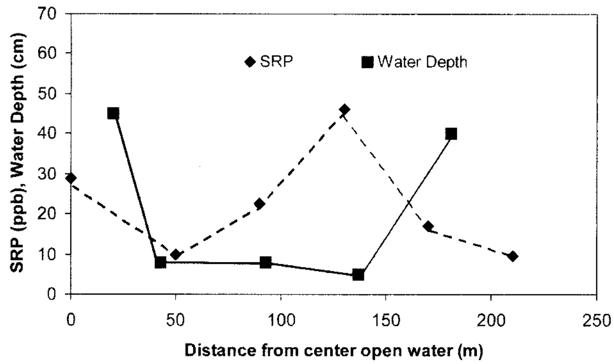

Figure 2. Soluble reactive phosphorus (SRP) content and water-holding capacity, based on water depth along line transect.

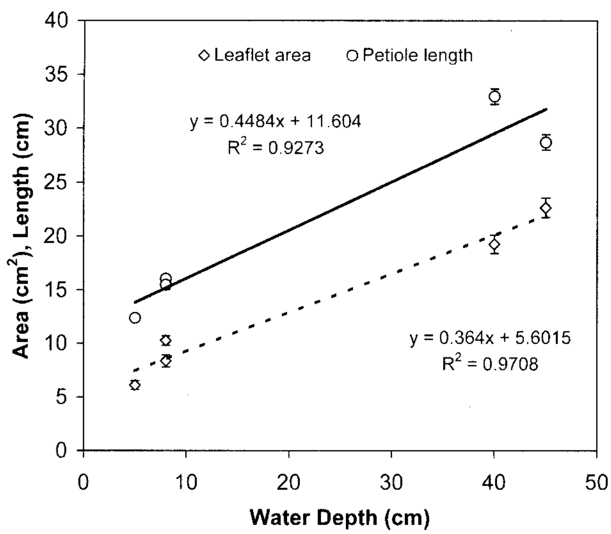

Figure 3. Relationships between leaflet areas and petiole lengths of *M. trifoliata* and water depth.

Total nitrogen content ranged from 0.62% (in the petiole) to 2.76% (leaf), while the amount of carbon was between 39.7% (petiole) and 43.8% (stem) (Fig. 5). The relationship was positive and statistically significant between petiole length and total nitrogen content in the leaflet ($p < 0.05$). Because values for total carbon were very similar for all plant tissue types and all samples, the result was a C/N ratio in the leaflet that was negatively correlated with petiole. For example, leaflets from large plants had higher nitrogen contents. However, the C/N ratios for petioles and stems were positively related, indicating a negative relationship between overall growth and nitrogen content. This demonstrates that the nitrogen was concentrated in the leaflet, a phenomenon possibly important in maximizing photosynthesis when nitrogen levels are inadequate. Because N was being translo-

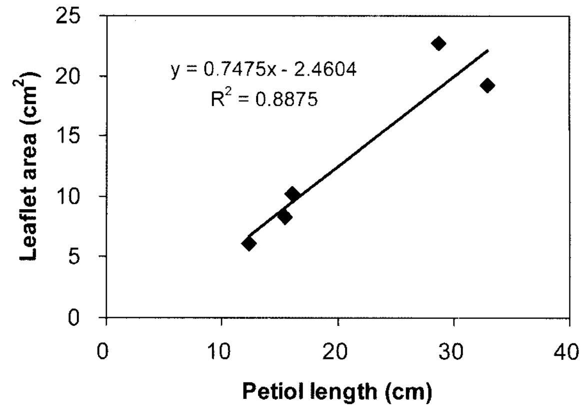

Figure 4. Positive relationship between petiole lengths and leaflet areas of *M. trifoliata*.

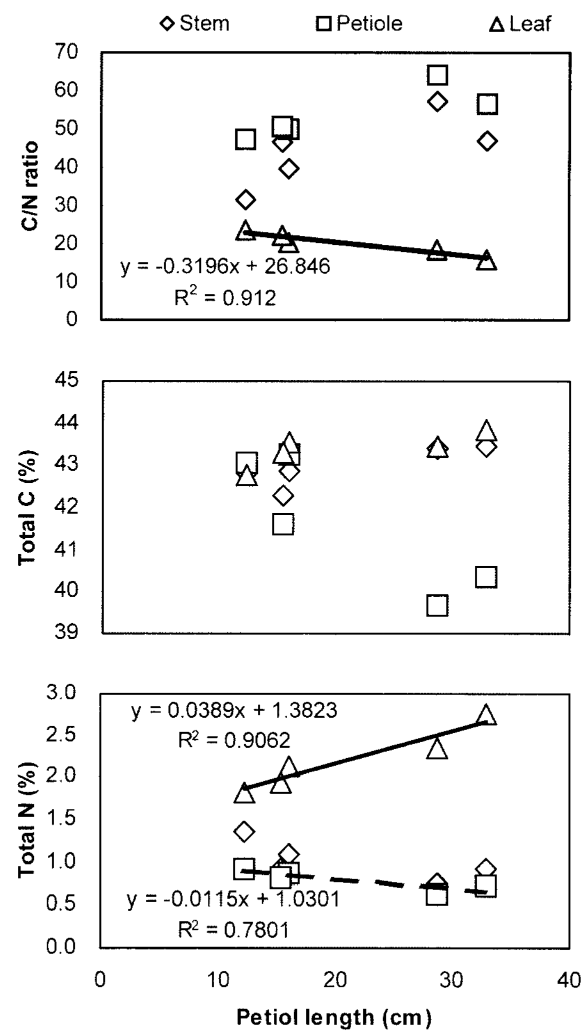

Figure 5. Relationships among petiole lengths, total C and N contents, and C/N ratios.

cated from the leaflets to the stems (rhizomes) after September (Haraguchi, 1996), we could discount its role in determining the growth of *M. trifoliata* at our study site.

The distribution of aquatic macrophytes in aquatic ecosystems, such as bogs, fen, or the shallow edges of oligotrophic lakes, generally is determined by levels of N and P (Mitsch and Gosselink, 2000). Sedges, such as *Carex* spp., as well as grasses, e.g., *Eriophorum* spp. and *Vaccinium* spp., grow well in nutrient-poor wetlands (Julie and Fennessy, 2001). Although *M. trifoliata* can be included in those groups, we did not find that those elements were important factors in limiting its growth. Rather, we showed here that the capacity to hold water by a peat mat (as measured by water depth) determined the success of *M. trifoliata* populations on Grass Lake. Therefore, our study results provide insight into the means for restoring this species by demonstrating that its habitat could be improved by creating floating mats to retain large quantities of water on such oligotrophic sites.

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