J. Aquat. Plant Manage. 46: 186-189

Predicting Invasion of European Frogbit in the Finger Lakes of New York

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INTRODUCTION

Many lakes in the United States have been occupied by non-indigenous and invasive species that have altered ecosystem functions (Mills et al. 1994, Ricciardi 2001, Zhu et al. 2006, 2007). Predicting future invasion success of these species is important for allocation of resources to prevent invasions (Madsen 1998). These lakes are also undergoing environmental changes associated with global warming, which may affect the growth and spread of invasive species (Rybicki and Carter 2002, Verburg et al. 2003, van der Heide et al. 2006). Predicting invasion success requires understanding the response to these environmental changes. In addition, lakes with different trophic levels may have different potential for invasive success (Madsen 1998, Hummel and Kiviat 2004). In this study, we investigated whether the invasive non-native aquatic plant European frogbit (*Hydrocharis morsus-ranae* L.) is likely to invade the oligotrophic-mesotrophic Finger Lakes of New York State given the range of trophic conditions in these lakes and the predicted increase in temperature over the next century.

European frogbit is a floating aquatic plant that reproduces vegetatively through development of stolon buds and turions (Catling et al. 2003). European frogbit is native to Eurasia and was first introduced to North America in 1932 in an arboretum in Ottawa, Canada, via specimens from Switzerland (Minshall 1940). It escaped to the Rideau Canal system in 1939, spreading rapidly by means of water movement, birds, boats, and humans. In 1974, the plant invaded the St. Lawrence River in New York, United States (Roberts et al. 1981). Since then, it has spread south and west to Lake Ontario, south to Lake Champlain north of the Hudson River, and west to Lake Erie (Catling and Porebski 1995, Catling et al. 2003). Recently it was reported in Michigan and Washington (Catling et al. 2003). Similar to water chestnut (*Trapa natans* L.), European frogbit can form dense floating mats and has detrimental effects on native aquatic vegetation by blocking light, on animals by reducing food plants and dissolved oxygen, and on human commercial and recreational activities by interfering with boating, fishing, swimming, and hunting (Hummel and Kiviat 2004). European frogbit reached a local density of 512 plantlets/m^2 in some bays of Oneida Lake, and dissolved oxygen (DO) concentrations as low as 1.9 mg/L were reported underneath the plants (Zhu, unpublished data). European frogbit has the potential to become a major weed with substantial environmental and economic impacts in the United States, especially in the northern states such as New York.

The 11 Finger Lakes are located south of Lake Ontario and east of Lake Erie in close proximity to the current range of European frogbit (Catling et al. 2003). Water quality is generally categorized as oligotrophic to mesotrophic with total phosphorus (TP) concentrations ranging from 4.0 to 24.2 µg/L (Callinan 2001). European frogbit is believed to favor mesotrophic lakes (Madsen 1998, Catling et al. 2003), similar to other invasive, non-native aquatic plants, such as Eurasian watermilfoil (*Myriophyllum spicatum* L.), and may have difficulty invading the relatively low productivity Finger Lakes. However, the response of European frogbit to different nutrient levels has not been tested experimentally and the plant has been found in the Oneida River, which connects to the Finger Lakes (Zhu, unpublished data). Higher water temperatures (to 30 C) have been reported to promote growth of aquatic plants (Santamaria and Hootsmans 1998, Rybicki and Carter 2002, van der Heide et al. 2006). Increasing water temperature associated with predicted climate change may therefore increase the likelihood of invasion success by European frogbit in the Finger Lakes. Our goals in this study were to investigate the growth of European frogbit under two temperatures (simulating current and future temperatures) and two TP concentrations (simulating oligotrophic and mesotrophic lakes), and to infer its invasion success in the Finger Lakes.

MATERIALS AND METHODS

We used a fully factorial experimental design (2 × 2 × 5): two temperatures (25 and 30 C), two TP concentrations (19 and 36 µg/L), and five replicates for each treatment. We collected nearshore Seneca Lake water (TP = 19 ± 2.1 µg/L, mean ± SE) because European frogbit usually starts to establish close to shore. Seneca Lake is typically considered as oligotrophic lake and has a relatively low nutrient concentration lakewide, about 8.5 µg/L TP in 2007 (J. D. Halfman, Hobart and William Smith Colleges, unpublished data), but nearshore waters often have higher nutrient concentrations than the offshore, especially in dreissenid-invaded lakes (Hecky et al. 2004). We dissolved KH_2PO_4 into Seneca Lake water to simulate mesotrophic conditions with TP of 36.3 ± 1.3 µg/L. Twenty individual plants of European frogbit with similar sizes, collected from Oneida Lake, New York, were randomly placed in 20 white plastic containers (diameter = 0.3 m and height = 0.35 m) with 15 L of water in each container (one plant per container). The containers were divided into four groups based on the four treatments:

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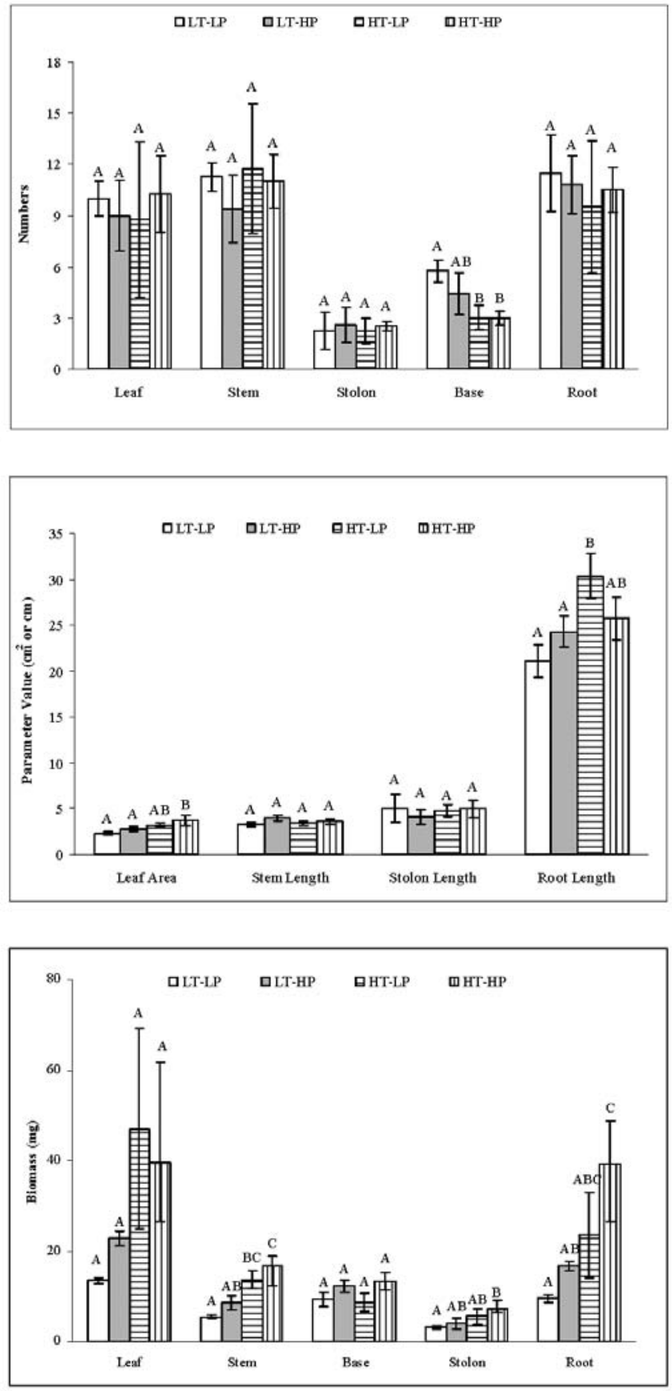
A. temperature 25 C and TP 19 µg/L (LT-LP); B. temperature 25 C and TP 36 µg/L (LT-HP); C. temperature 30 C and TP 19 µg/L (HT-LP); and D. temperature 30 C and TP 36 µg/L (HT-HP). Groups of LT-LP and LT-HP were transported and arranged randomly in one growth chamber (Conviron E15, Controlled Environments Ltd, Winnipeg, Manitoba, Canada) with temperature at 25 C, and the other two groups were in another chamber with temperature at 30 C. The maximum light intensity (~830 µmol/s/m^2) was applied for 14 hours each day for 21 days in July 2007. The position of the containers was randomly switched each week to decrease potential differences in light intensity at different locations in the growth chamber.

To ensure a similar growth environment for plants at the beginning, we measured pH and DO concentrations for each container using a YSI 556 Multiprobe System (YSI, Inc., Yellow Springs, OH) and TP following the procedures of APHA (2005). We also measured the attributes of the plants: leaf number, leaf area, stem number, stem length, root number, and root length. At the end of the experiment, we measured the same variables as well as stolon number, stolon length, base number (indicating number of plantlets), and biomass for all the parts of the plants. Biomass was weighed after drying at 65 C for 72 hrs when a constant weight was achieved. Data were analyzed using ANOVA (GLM procedure of SAS 9.0, SAS Institute, Cary, NC) to test the temperature and phosphorus effects (Kuehl 2000). No transformations were needed following tests for heteroscedasticity. All ANOVA was followed by least significant difference (LSD) analysis to compare different treatments at the level $\alpha = 0.05$. Due to phosphorus contamination in two containers and plant consumption by a snail in one container, only 17 of 20 samples (4, 5, 4, and 4 in each group) were included for analysis. We used the Type III sum of square methods to determine the main effects of TP and temperature because the discrepancy in sample sizes was small and the consequence of unequal sample size was negligible.

RESULTS AND DISCUSSIONS

The initial pH and DO concentrations did not differ among the four groups (ANOVA, df = 3, F = 0.35, p = 0.787 for pH and df = 3, F = 0.66, p = 0.592 for DO), and there were no significant differences in plant leaf number, leaf area, stem number, stem length, root number, and root length among the four groups at the beginning of the experiment ($p > 0.05$). Concentrations of TP were higher in groups with phosphorus addition (df = 1, F = 84.8, $p < 0.001$). Thus, the initial differences of TP concentration and temperature among treatments were likely to contribute to the differences observed at the end of experiment.

We found temperature had mixed effects on European frogbit. Higher temperature significantly reduced the base number from 5.5 ± 2.0 (mean ± SE) to 3.0 ± 1.1 (df = 1, F = 5.25, p = 0.039) whereas numbers of leaves, stems, stolons, and roots did not differ (Figure 1A). Because each base represents a plantlet, the results indicate there were fewer plantlets at higher temperature. In contrast, higher temperature induced greater leaf area (+36.8%) and root length (+23.6%) (df = 1, F = 8.04, p = 0.005 and df = 1, F = 6.31, p = 0.013 respectively; Figure 1B). It also significantly increased stem biomass, stolon biomass, root biomass, and total biomass of each plantlet ($p < 0.05$; Figure 1C). These data suggest higher temperature promotes plant growth but not division;



A.

B.

C.

Figure 1. Responses of European frogbit at two temperatures and two total phosphorus concentrations in growth chambers: A. numbers of parts of the plant; B. measured values of parts of the plants; and C. biomass per plantlet of different plant parts. LT = Low Temperature (25 C); HT = High Temperature 30 C; LP = Low TP = 19 µg/L; and HP = High TP = 36 µg/L. Different letters denote significant differences among treatments at $\alpha = 0.05$ level using the LSD analysis in ANOVA.

therefore, it is difficult to evaluate the resulting effect of temperature on invasion success of European frogbit. Slower vegetative reproduction at higher temperatures would likely decrease their ability to spread at higher temperatures.

This finding is in contrast to our expectation that higher temperature would promote invasion success by promoting growth. Higher temperature often increases growth rates in aquatic plants (Rybicki and Carter 2002, van der Heide et al. 2006). For example, several floating species, including invasive giant salvinia (*Salvinia molesta* Mitchell) and several submerged macrophytes such as invasive hydrilla (*Hydrilla verticillata*), were found to reach their maximum growth rate at temperatures between 25 and 30 C. However, reproductive rates may be more important than individual growth for predicting invasion success. In this study, vegetative reproduction was markedly reduced at 30 C, suggesting lower likelihood of invasion success. This finding was surprising, but certainly not unique. For example, Santamaria and Hootsmans (1998) reported the optimal reproduction temperature for submerged macrophyte *Ruppia drepanensis* Tineo seedlings was 20 C whereas there was no reproduction at 30 C. Another study on sprouting of the tubers of Chinese water chestnut (*Eleocharis tuberosa* Roem) revealed the highest sprouting rate and speed occurred at 25 C when tested across a series of temperatures ranging from 15 to 30 C (Terabayashi et al. 2004). Therefore, global warming *per se* is not likely to facilitate invasion of European frogbit to new areas when the water temperature reaches over 30 C. Instead, it will probably inhibit plant reproduction (Figure 1A) and may limit future southern expansion of the species. However, temperature varies among years, and a maximum water temperature of 30 C may not be reached in the near future. For example, water surface summer temperature (Jun-Aug) in Oneida Lake averaged 21.2 C in 2000-2004, ranging from 14.3 to 26.8 C, and the mean summer temperature at 1-m depth in Seneca Lake was 20.1 C with a range of 10.4 to 28.4 C. The nearshore water temperature is expected to be higher than the temperature at 1-m water depth but is still lower than 30 C. Therefore the current nearshore temperature in the Finger Lakes is likely to promote the rapid growth rate (Figure 1B, C) and facilitate European frogbit's spreading in the Finger Lakes in the near future.

In this study, no significant TP effects were observed on plant growth or reproduction in terms of number, size, or biomass of different parts of the plants (ANOVA, all $p \gg 0.05$). We used the higher phosphorus concentration (36 µg/L) to simulate the nearshore water in mesotrophic lakes like Oneida Lake and Honeoye Lake (one of the Finger Lakes) and the nearshore concentration (19 µg/L) in oligotrophic Seneca Lake (TP = 8.5 µg/L lake-wide) to simulate more oligotrophic Finger Lakes. Therefore, our result indicated plant growth or reproduction did not differ between moderately oligotrophic and mesotrophic water. This has a significant implication for European frogbit invasion to oligotrophic lakes like the Finger Lakes. European frogbit should be equally able to invade oligotrophic lakes (at least moderately oligotrophic lakes) as to invade mesotrophic lakes where they are more commonly observed (Madsen 1998, Catling et al. 2003). Therefore the Finger Lakes would be susceptible to European frogbit invasion.

From these results, we concluded that mild gradual global warming would likely facilitate invasion of European frogbit in either oligotrophic or mesotrophic lakes by increasing growth rate, if not promoting the vegetative reproduction. We predict that the Finger Lakes of New York will likely be invaded by European frogbit in the near future. Thus, it is important to educate the public about this species. One possibility is the "adopt-a-shoreline" program in operation in several New York lakes that is designed to detect and eradicate invasive plants such as European frogbit and water chestnut (Amy Samuels, Cornell Cooperative Extension, pers. comm.). It is also important for aquatic plant managers to make informed decisions about invasive species control, with priority and resource allocation based on research.

ACKNOWLEDGMENTS

We thank Mr. Joseph Sullivan for assisting sample collection, Dr. John D. Halfman for Seneca Lake temperature and phosphorus data, Dr. Elizabeth Newell for proving experiment facility, and the Andrew W. Mellon Foundation for the financial support. This is contribution number 257 of the Cornell Biological Field Station.

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