Realizing a Biological Control for Water Chestnut (Trapa natans)

The Next Step - Proposal and Supporting Information

Water Chestnut Biological Control Interest Group

Information Collated *(with permission)* By:
Rob Williams, The Nature Conservancy – SLELO PRISM Coordinator

Host Specificity and TAG Petition Proposal By:
Bernd Blossey, PhD. Cornell University

Supporting Research Information:
Jianqing Ding, Bernd Blossey, Yuzhou Du, Fushan Zheng

Kristy Szprygada, Intern
CNY Regional Planning and Development Board

***In** New York State alone, 32 counties representing nearly 60% of the state now have water chestnut populations. Populations are found in 9-states in the northeastern United States including at least two Canadian provinces. Tremendous monetary and human resources have gone into the control of Trapa natans for many years. In the Oswego River alone nearly ½ million has been spent on mechanical harvesting and equal that amount on chemical treatments and that's just for one site totaling nearly 1-million. Add the work that has been done in Lake Champlain and other areas including central New York, both monetary and in-kind, estimates are in the millions to suppress water chestnuts. These costs are not subsiding – but increasing. Not to mention the continued impacts to the ecological integrity of our freshwater resources, tourism and recreation. Adding a biological control into our toolbox would be advantageous.*

The biological control interest group is an ad hoc group of individuals and organizations that have shown recent interest in pursuing a biological control as a management tool for water chestnuts. This ad hoc group stems from participation on a conference call in December 2013 and includes representatives from New York, Canada and Vermont. The lead contact for this group is Rob Williams, rwilliams@tnc.org

Biological Control of Water Chestnut: The Next Phase

Dr. Bernd Blossey
Department of Natural Resources, Fernow Hall, Cornell University
Email: bb22@cornell.edu; phone: 607-227-1572

Background:

Water chestnut (*Trapa natans*) invasions have negative ecological and economic consequences. State and federal agencies, municipalities, and Lake Associations spend millions of dollars for mechanical and chemical control. Funding for treatments needs to be maintained in perpetuity to contain water chestnut. Development of biological control offers a cost effective and ecologically sound alternative. We evaluated a leaf beetle, *Galerucella birmanica*, as a potential biocontrol agent between 2002 and 2005. This beetle is a pest of commercially grown water chestnut in China. Initial tests conducted in China showed that this beetle eliminates growth and defoliates rosettes. Furthermore, feeding tests on some 20 related plant species determined that this leaf beetle appears a safe and effective potential biocontrol agent. The development of biological control appears possible without jeopardizing native species.

Proposed Work Program:

A biocontrol agent release requires formal host specificity testing involving 40-50 native species. After testing, a petition for release is submitted to the Technical Advisory Group (TAG, within USDA/APHIS) for approval, followed by rearing and release if also approved by state agencies. We have re-established contacts with Dr. Ding, who did much of the work in China and at Cornell. Dr. Ding is prepared to coordinate the work in China where some of the host specificity tests and beetle collections will need to be carried out. In addition to the work to be conducted in China, we will need to work in a quarantine facility in the US to further test plant species that we can't test in China (available at Cornell University).

Budget:

Based on experience in similar programs, annual funding needs of $80-100K are anticipated. This will cover work in the US and China. A 3-5 year duration is anticipated based on level of funding and progress made in insect and plant rearing. This would include a formal submision of a petition to TAG. I am prepared to continue to coordinate the project and write the petition to TAG. A more detailed budget can be provided on request.

Median Cost: $90,000/year x 4 years = $360,000.00

For additional detailed information on the scientific progress please consult the following references:

Ding, J., and B. Blossey. 2005a. Impact of the native water lily leaf beetle *Galerucella nymphaeae* (Coleoptera: Chrysomelidae) attacking introduced water chestnut, *Trapa natans,* in the northeastern United States. Environmental Entomology **34**:683-689.

Ding, J., and B. Blossey. 2005b. Invertebrate predation on the water lily beetle, *Galerucella nymphaeae* (Coleoptera: Chrysomelidae), and its implications for potential biological control of water chestnut, *Trapa natans*. Biological Control **35**:17-26.

Ding, J., B. Blossey, Y. Du, and F. Zheng. 2006a. *Galerucella birmanica* (Coleoptera: Chrysomelidae), a promising potential biological control agent of water chestnut, *Trapa natans*. Biological Control **36**:80-90.

Ding, J., B. Blossey, Y. Du, and F. Zheng. 2006b. Impact of *Galerucella birmanica* (Coleoptera: Chrysomelidae) on growth and seed production of *Trapa natans*. Biological Control:doi:10.1016/j.biocontrol.2005.1012.1003.

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Impact of Galerucella birmanica (Coleoptera: Chrysomelidae) on growth and seed production of Trapa natans

Jianqing Ding [a,1], Bernd Blossey [a,¤], Yuzhou Du [b], Fushan Zheng [b]

[a] Ecology and Management of Invasive Plants Program, Department of Natural Resources, Fernow Hall, Cornell University, Ithaca, NY 14853, USA
[b] Department of Plant Protection, Yangzhou University, Yangzhou, Jiangsu 225009, PR China

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Abstract

Success in biological weed control programs depends upon the ability of host-speciWc herbivores to suppress populations of their host plant. While pre-release predictions of Weld host range (i.e., speciWcity) appear widely accurate, predictions about which agent or agent combination may suppress plant populations have lately been compared to predictions in a lottery. The history of weed biocontrol does not oVer immediately obvious approaches to improve the lottery model, however, pre-release assessments of the impact of diVerent herbivore densities on the invasive plant may provide an opportunity to improve predictions of success. In this paper, we report on the impact of the leaf beetle Galerucella birmanica on growth and reproduction of water chestnut, Trapa natans, in the native range in China. At low herbivore densities (10–50 larvae/rosette), plants compensated for leaf herbivory by increasing leaf production at the expense of reproductive eVort. Inoculating >50 Wrst instar larvae per rosette greatly suppressed biomass production and plants were unable to grow when three or more G. birmanica pairs were released per seven rosettes. In the native range, similar densities are found in the Weld, resulting in complete defoliation of T. natans. Our study indicates that G. birmanica feeding has signiWcant negative impacts on T. natans. This chrysomelid species appears to be a promising biological control agent and we would predict that the species will be able to attain suYciently high populations to control its host plant—if approved for release in North America.

Keywords: Herbivory; Biological weed control; Invasion; Water chestnut; Plant–insect interaction

1. Introduction

Success in classical biological weed control programs relies on the availability of host-speciWc control agents able to suppress target weed populations. While predictions about the realized host-speciWcity of herbivorous biocontrol agents based on pre-release evaluations have been overwhelmingly accurate (Blossey et al., 2001; Louda et al., 2003; McFadyen, 1998; Pemberton, 2000), forecasting control success has been much less successful and is often compared to a lottery (Crawley, 1989; Denoth et al., 2002; Lawton, 1985, 1990; McEvoy and Coombs, 1999). Historically, biocontrol scientists have used scoring systems (Goeden, 1983; Harris, 1973), climate matching (Wapshere, 1985), and more recently demographic models (Lonsdale, 1993; McEvoy and Coombs, 1999; Rees and Paynter, 1997; Shea and Kelly, 1998) to evaluate the promise of single or multiple potential control agents. While it is too early to assess the long-term success of demographic models, the traditional approach has clearly failed to provide the desired success rate (Blossey and Hunt-Joshi, 2003) or allow unequivocal prioritization of control agents (Blossey, 1995a). Thus, the currently existing protocols for selecting promising candidates commonly rely on expert opinion, while the overall desire is to develop a more reliable statistical, experimental, and mathematical foundation to allow reliable predictions about the success of biocontrol agents

* Corresponding author. Fax: +1 607 255 0349.
E-mail address: bb22@cornell.edu (B. Blossey).
[1] Present address: Center for Integrated Plant Systems, Michigan State University, East Lansing, MI 48823, USA.

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before they are released (McClay and Balciunas, 2005; McEvoy and Coombs, 1999).

A potential reason for the lack of predictability of success is the lack of pre-release impact studies that measure the eVect of herbivore feeding at diVerent densities on growth, survival, biomass production, and reproductive output of the target invasive plant (McClay and Balciunas, 2005). Most weed biocontrol programs spend the majority of their funding on host-speciWcity screening, while only a small proportion of funds is invested to study impact of herbivores on plant performance (Blossey, 1995b; Briese, 1996; Goolsby et al., 2004; Sheppard et al., 1995). Impact studies, whether conducted in the Weld through exclusion, or in common gardens through addition of herbivores, particularly in combination with demographic modeling, may eliminate scientiWc and monetary expenses that are spent on ultimately unsuccessful agents (McClay and Balciunas, 2005). Reducing the number of introductions of species that ultimately contribute little to control their target host will also have the additional beneWt of reducing the potential risk to non-target plants (McEvoy and Coombs, 2000).

In this paper, we report on impact evaluation of a potential biocontrol agent, Galerucella birmanica Jacoby (Coleoptera: Chrysomelidae), that attacks water chestnut, Trapa natans L. (Trapaceae), in the native range in China. Water chestnut is an annual aquatic plant of Asian origin, where it is an important food crop. The plant was introduced into North America around 1870 and has become invasive in the Northeastern United States and Canada (Pemberton, 2002). Chemical and mechanical means failed to provide long-term and economically sustainable suppression of T. natans, resulting in increased interest in biological control (Pemberton, 2002). Our study on the impact of the Asian G. birmanica complements a study evaluating the impact of a native North American herbivore, the water lily leaf beetle Galerucella nymphaeae L., on growth and reproductive output of T. natans (Ding and Blossey, 2005a). The native G. nymphaeae, although commonly found on T. natans in North America, experienced high mortality on T. natans and never reached high abundance; consequently the impact on T. natans growth and seed output was negligible and the species cannot be considered a potent potential native biocontrol agent (Ding and Blossey, 2005a).

In China and India, G. birmanica is considered the most important pest of water chestnut (Khatib, 1934; Lu et al., 1984; Pemberton, 1999), but initial concerns over lack of speciWcity of G. birmanica prevented further study of the species (Pemberton, 1999). These initial concerns appear to be based on erroneous reports and taxonomic confusion and recent preliminary host-speciWcity tests show the species as highly speciWc to T. natans (Ding et al., 2006). However, despite abundant anecdotal reports on the status of G. birmanica as a pest of cultivated T. natans in China, there is little quantitative information on the interaction of T. natans and G. birmanica. In particular, there is no information on the impact of diVerent G. birmanica attack rates on plant survival, growth, and reproduction, making predictions about the potential impact of the species after Weld release in North America diYcult. We evaluated the impact of G. birmanica adults and larvae on T. natans performance at diVerent densities in common gardens in Yangzhou, southeastern China. We use results of these impact studies to: (1) forecast the impact of G. birmanica should the species be approved for Weld release and (2) compare the impact of two closely related leaf beetles, G. nymphaeae and G. birmanica, on T. natans performance.

2. Materials and methods

2.1. Experimental organisms

Seeds of T. natans overwinter in shallow water bodies and produce rosettes in spring. A single rosette anchored in the hydrosoil may produce 10–15 daughter rosettes kept aXoat by spongy inXated leaf petioles. Each rosette can produce 15–20 woody nuts (containing a single seed), which ripen over time, dislodge from the plant, and sink to the bottom where they overwinter and may remain viable in water for up to 12 years (Kunii, 1988; Winne, 1935). In North America, T. natans can reach densities of up to 50 rosettes/m^2 that severely restrict most recreational activities such as swimming, Wshing from the shoreline, and use of small boats. Over much of its native range in Asia, the starchy nut-like fruits of T. natans and its various cultivars are used as food (Pemberton, 2002).

Adult G. birmanica overwinter onshore in the leaf litter and colonize T. natans as rosettes appear on the water surface each spring. Adults and larvae feed on the leaves creating typical "trenches" or "scars" by removing the upper epidermis and the parenchyma. Females lay clusters of 15–20 eggs, and larvae feed and pupate on a single rosette, although they may need to move from leaf to leaf as their host becomes defoliated (Lu et al., 1984). At high attack levels, entire leaf blades are consumed leaving only a skeleton of major veins and the spongy petiole. Larval development may take several weeks but depending on latitude, two–seven overlapping generations may develop. In northeastern China, G. birmanica may complete only one–two generations with adults disappearing from T. natans in mid-late August, while in southeastern China, beetles may have an aestivation period in the hottest summer months but are still able to complete at least six generations (Ding et al., unpublished data).

2.2. Adult–larval herbivory

In late May 2003, we collected unattacked similar sized T. natans plants for our experiments from a wild population near Guazhou (a suburb of Yangzhou City, Jiangsu Province, Southeastern China). We kept all plants in an outdoor artiWcial pond at the Department of Plant Protection, Yangzhou University. The pond bottom consisted of a shallow soil layer and we supplied liquid fertilizer (N–P–K: 8–8–9) as needed to maintain healthy plant growth. At the time of plant material collection, we also collected G. birmanica adults, larvae, and eggs from a separate wild T. natans population near Guazhou. We maintained the G. birmanica population on T. natans in a separate caged outdoor artiWcial pond at Yangzhou University.

We buried 15 containers (height 100 cm, diameter 60 cm, and water depth 80 cm; with a thin layer of soil at the bottom) 80 cm into the ground. Each container received seven T. natans plants (each with about 20 leaves). Each container was then randomly assigned to one of Wve treatments (0, 1, 3, 5, and 7 pairs of G. birmanica adults; n D 3 replicates per treatment). After we introduced adults on 2 June, 2003, we covered each container with mesh to prevent beetle escape. Adults were allowed to oviposit and larvae were allowed to complete their life cycle and their oVspring continued grazing the rosettes. We recorded the number of green T. natans leaves in weekly intervals until termination of the experiment in mid July.

2.3. Larval herbivory

In 2004, we used the same plant and insect sources, as well as the same plant rearing methods described under adult herbivory. We established 40 containers (50 cm diameter, 60 cm high, and water depth 50 cm) in a common garden at Yangzhou University. Each container was dug 50 cm into the ground and randomly assigned to one of four larval density treatments (0, 10, 20, or 50 G. birmanica; n D 10 replicates per treatment). We selected similar sized plants and transferred a single T. natans rosette (including stem and root) into each container in early June 2004.

To obtain Wrst instars, we removed eggs at regular intervals from plants kept in the rearing pond with G. birmanica adults and allowed larvae to hatch in petri dishes placed in a growth chamber (28–30 °C, 14 h photoperiod). Within 24 h after hatching, we inoculated larvae onto plants according to treatment in a staggered fashion. We closed each container with a gauze lid to prevent larval escape or colonization by feral G. birmanica, other herbivores or predators. We counted all larvae and pupae every 7 days, and removed teneral adults upon emergence. We also counted the number of green leaves every week. Once all adults had emerged, we repeated the inoculation of rosettes using identical larval densities in an attempt to simulate the naturally occurring number of generations of G. birmanica in this region of China. By the end of August, we had completed inoculation and emergence of six generations. At the termination of the sixth generation, we harvested all plants, counted the number of nuts, and dried the plants at 70 °C for 72 h in a drying oven and subsequently determined their biomass.

We chose our larval densities in the previous experiment based on similar densities used in impact studies with G. nymphaeae in North America (Ding and Blossey, 2005a) and to avoid complete and rapid mortality of the host plant (see adult–larval herbivory). However, our chosen larval densities appeared too conservative and did not create the near complete defoliation of rosettes often observed in the Weld. This limited our ability to forecast the needed larval densities that should allow for defoliation of rosettes. We therefore designed an additional experiment using seventh generation larvae inoculated at higher densities (0, 50, 100, and 150 G. birmanica L_1 per plant; n D 5 replicates per treatment). We chose an identical set-up as described for the previous larval herbivory experiment (where all rosettes had been harvested). We chose unattacked T. natans plants of similar size to be placed into each container and then inoculated Wrst instar G. birmanica in late August 2004 according to determined treatment level. After 2 weeks, we recorded the number of leaves and the number of surviving insects. We were unable to measure the impact on reproductive eVort due to the fact that nuts had formed on the rosettes before they were subjected to herbivory and the short duration of this high density treatment.

2.4. Statistical analysis

We used repeated measures ANOVA to assess diVerences in the number of green leaves per rosette in treatments with diVerent initial adult densities (using means of means in the analysis because we placed seven rosettes per container). We used one-way ANOVA's to assess the inXuence of diVerent larval densities (0, 10, 20, and 50) on the number of leaves, biomass, and reproductive output (nuts per rosette) of T. natans. We used two-way ANOVA's to compare Wnal larval survival rates among diVerent larval density treatments of diVerent generations. Within larval generations 1, 3, and 6, we used repeated measures ANOVA to assess potential diVerences in larval survival rates among diVerent density treatments. We used one-way ANOVA's to assess diVerences in the number of green leaves remaining on T. natans, number of larvae and larval survival rates in treatments with high larval feeding pressure (0, 50, 100, and 150 larvae per plant). DiVerences among treatment means were analyzed using Tukey's HSD test and all data were analyzed using Statistica 6.0 (StatSoft, Tulsa, OK).

3. Results

3.1. Adult–larval herbivory

The number of leaves per rosette did not change for the control (repeated measures ANOVA, $F_{6,18}$ D 1.779, P D 0.1602) and the one pair treatment over the duration of the experiment ($F_{6,18}$ D 1.032, P D 0.3844) (Fig. 1). There were no signiWcant diVerences in the number of leaves per rosette among treatments at week 2 ($F_{4,20}$ D 1.171, P D 0.3801). However, continued heavy herbivory by adults and their oVspring in all but the control and the one pair treatment resulted in complete collapse of T. natans and the number of leaves per rosette dropped from 18–20 to 0 and plants did not recover (Fig. 1). In addition to the adults, the average number of G. birmanica second and third instar larvae per container was 178, 325, and 470 for the 3, 5, and 7 pair treatments, respectively. We had to abandon this

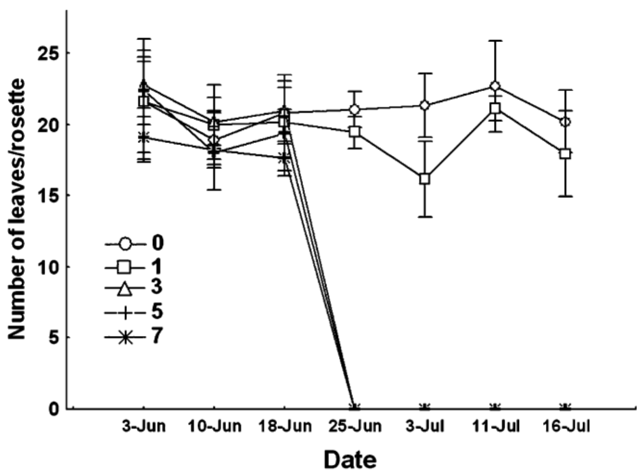

Fig. 1. Impact of diVerent G. birmanica adult densities on the number of T. natans leaves per rosette. Data are means of means of seven rosettes per container § 2 SE of three replicates per treatment.

experiment due to lack of food and survival in the medium and high density treatments.

3.2. Larval herbivory

As larval densities increased, plants maintained the number of leaves per rosette ($F_{3,36}$ D 2.274, P D 0.0965), however, increasing herbivory resulted in reduced total plant biomass ($F_{3,36}$ D 3.034, P D 0.0416) and reduced reproductive output ($F_{3,36}$ D 4.027, P D 0.0144) (Fig. 2). Larval performance was greatly aVected by local weather conditions and heavy rainfall resulted in substantial or near complete mortality of larvae in the second, fourth, and Wfth generations, which may have limited the overall impact of herbivory. Final larval survival rates (L_1–adult) of the Wrst, third, and sixth generation ranged from 15 to 43% with the lowest survival rates at the highest larval density (Fig. 3) and diVerences in survival rates among treatments were signiWcant ($F_{2,79}$ D 15.296, $P < 0.001$). Larval survival rates in diVerent density treatments varied signiWcantly in diVerent weeks ($F_{2,54}$ D 110.815, $P < 0.001$), for example in the third generation, larval density had a signiWcant eVect on larval survival rates ($F_{2,27}$ D 8.307, P D 0.0015). However, there was no signiWcant interaction between larval densities and time of inoculation ($F_{4,54}$ D 0.8804, P D 0.48). For the generations we were able to analyze (Wrst, third, and sixth), we found no signiWcant eVect of generation on survival rates ($F_{2,79}$ D 1.848, P D 0.1643) and there was no signiWcant interaction of generation and Wnal larval survival rates at diVerent densities ($F_{2,79}$ D 1.168, P D 0.3311).

With increased herbivory beyond 50 larvae per treatment, the number of leaves per rosette decreased substantially ($F_{3,16}$ D 15.53, $P < 0.001$) (Fig. 4). ConWrming results of our previous larval inoculation treatments, inoculating 50 L_1 per rosette did not result in changes in the number of leaves per rosette (Fig. 4), but at higher larval densities (100 and 150 larvae per rosette) rosettes could not compensate for herbivory and showed reduction in the number of leaves compared to the control (Fig. 4). When we terminated the experiments after 2 weeks, diVerences in survival rates (L_1–L_3/pupa/adult) among treatments were not signiWcant ($F_{2,12}$ D 0.61, P D 0.5582) and survival rates were comparable to earlier treatments (Fig. 3).

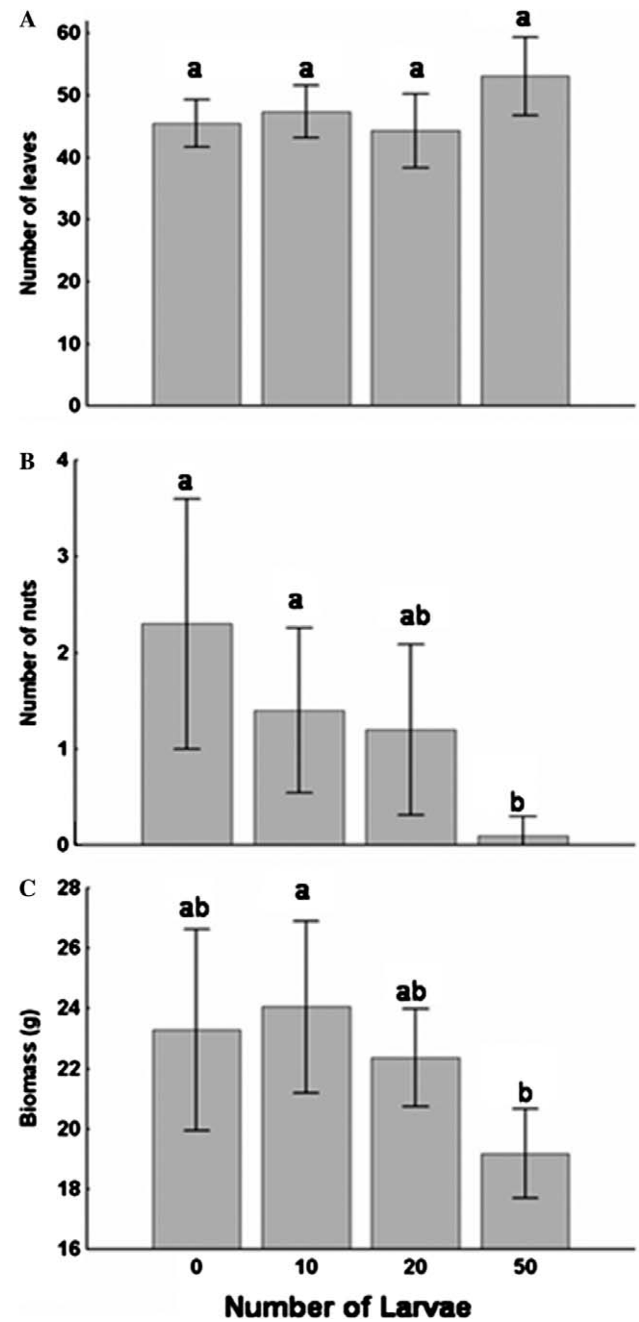

Fig. 2. Impact of 0, 10, 20, and 50 Wrst instar G. birmanica larvae on the numbers of leaves (A), number of nuts (B), and T. natans biomass (C) per plant. Data are means § 2 SE of 10 replicates per treatment. DiVerent letters above each column indicate signiWcant diVerences among treatment means (Tukey test, $P < 0.05$).

4. Discussion

Our study on the impact of G. birmanica on T. natans was motivated by the desire to better understand the

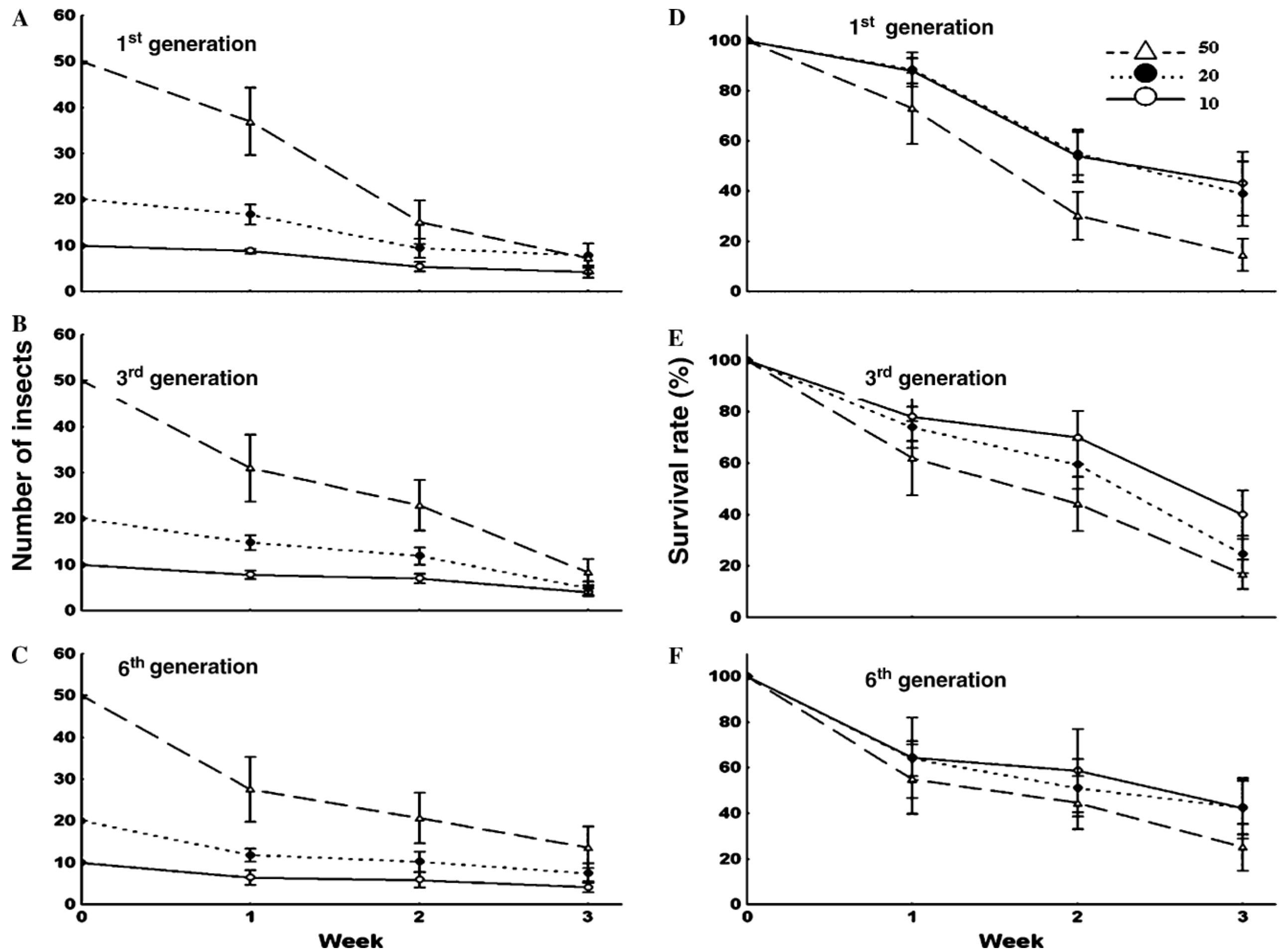

Fig. 3. EVect of diVerent larval densities (0, 10, 20, and 50 L_1 per rosette) and larval generation (Wrst, third, and sixth) on the number of surviving G. birmanica (A–C) and survival rates (D–F; %) from inoculation of L_1 to adult emergence. Data are means § 2 SE of 10 replicates per treatment.

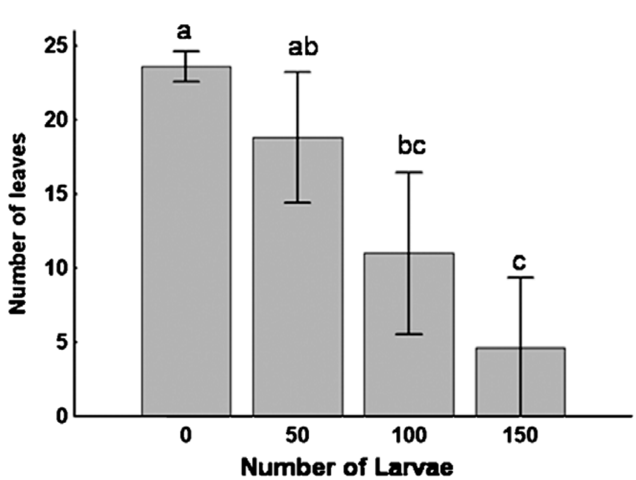

Fig. 4. Number of green T. natans leaves per rosette at diVerent G. birmanica larval densities. Data are means § 2 SE of Wve replicates per treatment. DiVerent letters above each column indicate signiWcant diVerences among treatment means (Tukey test, $P < 0.05$).

interaction of herbivore and host plant. This information would enable an informed decision regarding the prospects and likelihood of success for a biological control program targeting T. natans in North America. While previous anecdotal evidence has indicated pest status of G. birmanica on cultivated T. natans in Asia (Khatib, 1934; Lu et al., 1984), our results are the Wrst to demonstrate that densities as low as 0.5 G. birmanica pairs per rosette and their resulting oVspring can lead to complete defoliation of T. natans. While plants were able to compensate for loss of leaf biomass through increased leaf production at low herbivore densities (<50 larvae per rosette or 1 pair per 7 rosettes), even this low level herbivory resulted in reduced reproductive output. Higher herbivore densities resulted in the inability of plants to compensate for leaf loss and resulted in defoliation and plant death. Field surveys in southeastern and northeastern China suggested that the range of densities employed in our experiments are within the range of beetle or larval densities commonly encountered in the Weld. Ding et al. (unpublished data) surveyed wild T. natans populations in Jiangsu Province and recorded densities of 1.7–15 adults per rosette in June while in northeastern China densities in June and July were 0.5–0.7 adults per rosette. Densities of G. birmanica in southeastern China in June reached 65 adults, eggs, and larvae per rosette (Zheng, 2004) in 2003 and 30–50 larvae pupae and adults per rosette

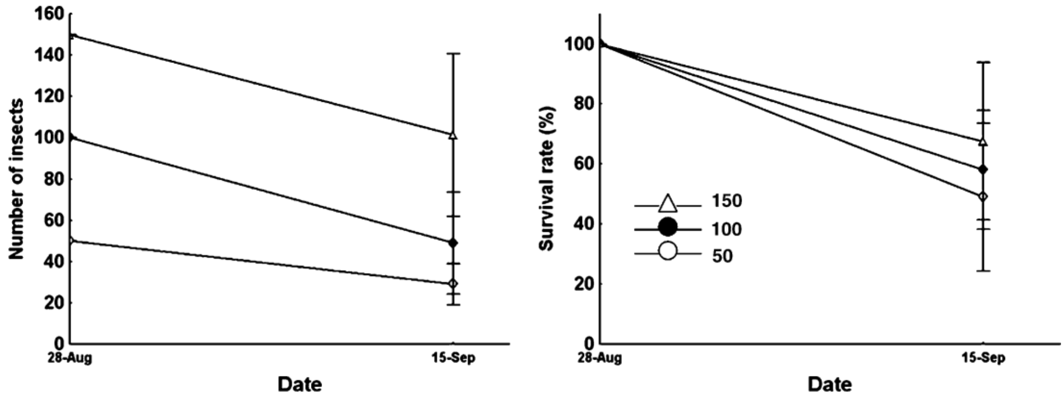

Fig. 5. EVect of diVerent G. birmanica larval densities on larval survival rates (%) and the number of live larvae after 18 days. Data are means § 2 SE of Wve replicates per treatment.

in 2004 (Ding et al., unpublished data). These data correspond well to the number of surviving larvae in our herbivory experiments, with the exception of the starting density of 150 L_1 per rosette in the high density treatment, which exceeded commonly found larval densities in the Weld. Somewhat similar data are reported from Japan, where the closely related Trapa japonica Flerov is grazed by Galerucella nipponensis Laboissier with 20–60 larvae and adults per rosette resulting in defoliation, while at low herbivore attack plants compensate by increasing the number of new leaves at the expense of decreased reproduction, reduced seed weight, and delayed Xowering (Ikeda and Nakasuji, 2003) (Fig. 5).

These data from the native range of T. natans suggest that, if shown suYciently host speciWc (Ding et al., 2006), G. birmanica can be expected to be a potent biological control agent. The herbivore is able to reach outbreaking densities in the native range that suppress reproduction and entire T. natans populations. The species occurs over a wide geographic range in Asia, including areas in northeastern China that are climatically similar to the invaded areas in northeastern North America. In addition, the species is extremely easy to work with and appears free of adult, egg, larval, or pupal parasitoids. In rearing thousands of Weld-collected pupae, adults, eggs, or larvae we never encountered parasitoids. While this appears unusual for insect herbivores, where external feeders such as G. birmanica, typically are expected to host four or more parasitoid species (Hawkins, 1990), the related G. nymphaeae L. feeding on Nuphar lutea L., yellow water lily, is also often reported to be parasitoid free (Ding and Blossey, 2005b; Kouki, 1993). In contrast, two closely related species, Galerucella pusilla Duftschmidt and Galerucella calmariensis L. feeding on the wetland perennial Lythrum salicara L., purple loosestrife, are attacked by egg, larval, and adult parasitoids (Blossey, 1991). We can only speculate that the feeding niche, with adults, eggs, and larvae feeding on Xoating aquatic vegetation, may be responsible for the lack of parasitoid attack, since chemical protection through plant derived compounds appears typically insuYcient to prevent attack by specialized parasitoids (but may oVer some protection from predation) (Gentry and Dyer, 2002; Hilker, 1992, 1994).

The lack of specialized parasitoids immediately raises the question of how population regulation occurs in the T. natans–G. birmanica system. In addition to predation by a variety of invertebrates (Ding and Blossey, 2005b; Nechols et al., 1996) or Wsh (Juliano, 1988) reported for G. nymphaeae, in our rearings of both G. birmanica and G. nymphaeae we encountered high mortality associated with Xuctuating water levels due to heavy rainfalls. Submergence of leaves over extended periods (>24 h) will result in G. nymphaeae larval death (Juliano, 1988) and we believe that heavy rainfall during the second, fourth, and Wfth generations of larvae in our experiments at Yangzhou University caused heavy G. birmanica mortality. Despite the impact of predation and climate events, G. birmanica was able to build suYciently high populations in the Weld to devastate T. natans populations. At present it appears that a switch of top-down and bottom-up forces regulates this plant–herbivore interaction. High T. natans populations allow leaf beetles to build large populations, resulting in plant population collapse (top-down control) and leaf beetles are forced to leave the host plant patches due to lack of food (bottom-up control) (Ding et al., 2006). Plant populations usually recover through regeneration of meristems if not completely defoliated or through germination from the seed bank, allowing renewed colonization by G. birmanica.

We currently lack long-term data to assess how this interaction may aVect the population status of T. natans in North America, if G. birmanica is approved for Weld release. The climate in northeastern North America, the current core T. natans distribution, would suggest that two generations of G. birmanica can complete their development, similar to results obtained in northeastern China. From our data, we expect that spring adult densities of 0.5–1 per rosette or 50–100 larvae per rosette will result in substantial defoliation of T. natans while plants will be able to compensate for lower attack rates (albeit at the expense of reproductive eVort). Partial or complete defoliation and reduced seed output is therefore expected to reduce populations of this annual plant within a few generations, particularly if native plant species are able to recolonize T. natans beds. We expect that herbivore feeding will allow continued light penetration into the water allowing for growth of competing plant species. However, North American T. natans may have evolved during >100 years of largely enemy free space and may have become more susceptible to specialized herbivory or more competitive (Blossey and Nötzold, 1995; Bossdorf et al., 2005), and we cannot exclude the possibility that such changes may aVect the interaction of herbivore and host plant.

Our experiments with G. birmanica allow an interesting comparison with similar experiments conducted with G. nymphaeae in North America (Ding and Blossey, 2005a). The native G. nymphaeae is commonly found on T. natans in North America but appears to have no impact on plant populations and our experiments using diVerent larval densities (10–50 L_1 per rosette) showed a complete lack of impact on T. natans biomass production or reproductive eVort (Ding and Blossey, 2005a). Similar densities of G. birmanica, while not aVecting the number of leaves, resulted in reduced biomass, and reproductive eVort of T. natans (Fig. 2). While we cannot exclude that diVerences in plant genotypes, nutrients, climate, and other abiotic factors between Asia and North America may contribute to the observed result, we consider diVerences in survival rates the most important contributor to the discrepancies in the impact of these two herbivores. Larval survival rates (L_1–adult) on T. natans (in the absence of predation) was typically 5–11% for G. nymphaeae and larvae died in early instars (Ding and Blossey, 2005a), while survival rates for G. birmanica were 15–43% at the same larval densities (Fig. 3). Typical survival rates for G. nymphaeae on suitable host plants range from 30–40% (Pappers et al., 2002). Early larval mortality of G. nymphaeae indicates lack of adaptation to this new host plant and this may involve chemical as well as physical or behavioral factors. Initial rejection of T. natans by L_1 may lead to increased foraging for an acceptable host and subsequent mortality due to drowning of larvae in the Weld. Laboratory experiments using individual T. natans leaves in petri dishes, show that larvae can complete development on T. natans and survival rates of G. nymphaeae were >80% (Ding and Blossey, unpublished data).

However, despite the ability of G. nymphaeae to develop on T. natans, the species cannot be considered a potential biological control agent. High mortality and the resulting lack of impact on plant performance combined with a continued preference for the native host, N. lutea, in choice experiments for beetles developing on T. natans (Ding and Blossey, unpublished data), prevents the use of G. nymphaeae even in augmentative releases. The Asian G. birmanica, if found suYciently host speciWc for release in North America, currently represents the most promising option to manage T. natans with biological control.

Acknowledgments

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Regional Water Chestnut Investigation Project Summary Report

Kristy Szprygada, Intern
CNY Regional Planning and Development Board, 2002

Introduction

Water chestnut, *Trapa natans*, is a highly aggressive invasive plant. Native to Asia, it was first recorded in North America near Concord, Massachusetts in 1859.[1]

Water chestnut plants can reach up to 16 feet in length. They produce a white flower with four petals up to 1/4 inch long and bloom from late June to September. Germination occurs in the springtime; one seed can give rise to 10-15 rosettes, each of which can produce 15-20 seeds. This annual plant has a high reproductive capacity. Each seed can produce 300 new seeds in a single year. One acre of water chestnut can produce enough seeds to cover 100 acres the following year.[1] Each plant produces a nut that has four extremely sharp horns connected to a spine with several barbs. The mature nuts sink to the bottom, can withstand drying and other extreme environmental conditions, and germinate up to 8-12 years later. Dispersal of the water chestnut is limited to the rosettes detaching from their stems and floating to a new area or displacement of the nuts by waves, winds, or human and wildlife interactions. The nut is the only part of the plant that will overwinter successfully. (Parts taken from the Oswego County EMC Water Chestnut Alert fact sheet)

In the Spring 2002 issue of the Cayuga Lake Watershed Network newsletter, J. DeHollander (Oswego Co. SWCD) wrote "It now consumes well over 100 acres of our beautiful, quiet interior waterways, and its range is ever expanding." Population estimates have exceeded 200 acres in CNY, since the Summer of 2002. This highly invasive plant can wipe out native bay grasses, prevent nearly all water recreation use where it occurs, create breeding grounds for mosquitoes, and provide only marginal habitat to native fish and birds.[1] Once an area is infested with water chestnut, it is only a matter of time before the channel is deemed unnavigable due to the dense mat of aquatic vegetation taking over the surface waters.

Public awareness and cooperation, along with public agency control efforts are required to eliminate water chestnut from our waterways and prevent its spread into new areas. Mechanical harvesting and hand pulling are two methods to help control the populations, but follow-up "maintenance" harvesting must be done to keep the areas free of future infestations. (Parts taken from the Oswego County Water Chestnut Alert fact sheet).

Water Chestnut: County Concern and Work Effort Summary

The DEC Region 7 office has received numerous complaints and concerns about water chestnut infestations within Onondaga, Oswego and Cayuga counties. Recently, the Central New York Regional Planning and Development Board (CNY RPDB) was assigned to determine the extent of the problem and summarize the education, outreach and control measures that have been taken throughout the five county region. This report is a summary of the CNY RPDB's investigation, broken up by county, to describe the extent of infestation, areas of concern, funding proposals and work efforts in each area. A GIS map was created to depict the areas of infestation summarized by this report (see Attachment 1). The original map, created by John DeHollander of the Oswego County Soil and Water Conservation District (SWCD), was a topographic paper map. It was then given to Scott Ingmire, of the Madison County Planning Department, who turned it into a GIS map. The CNY RPDB then updated it to include recent and more heavily infested areas since the Oswego County SWCD original paper map was created.

County Assessments

Cayuga: Cayuga County Cornell Cooperative Extension (CCE) is working in conjunction with the Cayuga Lake Watershed Network and the Owasco Watershed Lake Association (OWLA) to help educate the public on the identification and prevention of water chestnut. Their main concern is that the infestation in the Seneca River will make its way into Cross Lake and Cayuga Lake. In particular, they are closely monitoring the north end of Cayuga Lake; that is where they feel conditions are most favorable for an infestation. Their public education efforts have consisted of news releases, newsletters, aquatic plant workshops, and signs (made by the NYS DEC) posted at county lakes. There is also a display at the Cornell Cooperative Extension office that instructs the public on how to identify water chestnut and what to do if they find it in their area. Cayuga County CCE, the Water Quality Management Agency (WQMA), DEC, Cayuga County Planning Department, and the lake associations have organized an informal coalition of members to spread awareness and discuss strategies to prevent the spread of water chestnut into Cayuga County. In terms of funding, a proposal has been submitted to the Great Lakes Protection Fund by the Cayuga County CCE that would fund the continuation of their public education efforts and initiate monitoring programs throughout the county. (As per 7/02 phone conversation with Kelly Fallone, Cayuga County CCE)

According to the WQMA report distributed in June 2002, the Cayuga Lake Network, CCE of Cayuga County, Planning Department, SWCD, and OWLA have been active in developing and organizing educational programs for invasive species in the watersheds of Cayuga and Owasco Lakes. In Duck Lake, initiatives to design programs that encourage education and awareness of the dangers of spreading unwanted weeds and zebra mussels have been developed. The Cayuga County Planning Department is also searching for funding to inventory and map aquatic vegetation in Owasco Lake, to train CCE and Planning Department personnel to identify aquatic vegetation and to initiate a regular inventory and monitoring program for exotic and invasive species in Owasco Lake and its watershed.

[1] http://www.dnr.state.md.us/bay/sav/water_chestnut.asp

Cortland: Cortland County does not have water chestnut in any of its waterways, as of the Summer of 2002. Recognizing the possibilities of future infestations, Cortland County SWCD representatives would like to be kept up to date on the spread of this invasive plant. Educational/awareness/identification brochures could be distributed to county residents to keep them informed of the consequences of a water chestnut infestation, before it takes hold in Cortland County. (As per 6/02 phone conversation with Patrick Reidy, Cortland County SWCD)

Madison: The Madison County Planning Department is working closely with the Onondaga County DOH and the Oswego County SWCD to keep current populations of water chestnut under control and prevent the spread into Madison County. Pamphlets and brochures are available to Madison County residents which inform them of the water chestnut's potential to invade their area. Large educational signs, designed by Madison County Planning Department (with the help of the Oswego Co. SWCD), were placed at DEC boat launches, marinas, and waterfront parks to help the public identify the invasive plant; while learning how to control its spread via transport on or in their boats and recreational equipment. Madison County agencies have been assisting in the development and execution of programs, including hand-pulling and mechanical harvesting sessions to help remove water chestnut from the Oneida Lake and Three Rivers area; preparing many large signs for use in public education and outreach efforts; and seeking funding for future work with water chestnut. The highly favorable areas for water chestnut infestations are some of the shallow, slow moving, mucky bottom tributaries of the lake (e.g., Cowaselon Creek). These waterways are being watched closely by the Madison County Planning Department to ensure that water chestnut does not become established. At this time, water chestnut has not been reported in any waterbody within Madison County. (As per many Summer 2002 phone conversations with Scott Ingmire, Madison County Planning Department)

Onondaga: Mechanical harvesting and hand-pulling programs have been implemented in the Three Rivers area and the Western Basin of Oneida Lake to help contain and eradicate water chestnut populations. There have been no reports of water chestnut presence in Cross Lake. Funding has been secured from the Fish and Wildlife Foundation to develop public education and harvesting programs based on multiple-year goals (see Attachments 2 and 3). Working closely with Madison and Oswego Counties, the goal is to remove existing populations of water chestnut from Oswego and Onondaga Counties and to prevent future infestations into these two counties as well as into Madison County.

In order to prevent future infestations and control current populations, public education along with hand-pulling and mechanical harvesting methods are being used. CCE of Onondaga County has focused their efforts towards educating the public on the identification of and control measures for water chestnut in local waterways. They held two hand-pulling sessions in the summer of 2002 on the southwestern shores of Oneida Lake. In total, approximately 70 people representing the Boy Scouts of America, the Oneida Lake Association, CNY RPDB, CCE and lakeshore communities participated in the event.

CCE and other agencies in Onondaga, Madison and Oswego counties intend to continue these programs (education, hand pulling, mechanical harvesting) in the future and expand the harvesting practices to infested waterways in Onondaga County in addition to Oneida Lake. (As per 7/02 phone conversation with Russ Nemecek, Onondaga County DOH and 6/02 and 7/02 phone and in-person communications with Sheila Myers and Amy Samuels, CCE of Onondaga County)

Oswego: In the summer of 2001, John DeHollander surveyed Oneida Lake and the Seneca, Oswego, and Oneida Rivers to determine the extent of water chestnut infestations and assess the level of public awareness of the problem. A topographic map was produced with dots used to denote water chestnut presence. DeHollander found that most people were not able to identify the aquatic vegetation as water chestnut, but recognized it as a problem in their local waters. Working closely with Onondaga and Madison County agencies, grants have been proposed and funding secured for mechanical harvesting, public education programs and hand-pulling sessions. (As also referenced in the Onondaga and Madison County sections.)

The Oswego County SWCD has been in charge of conducting the mechanical harvesting in Oneida Lake through funds administered by the Oswego County Planning and Community Development which were provided through annual Finger Lakes - Lake Ontario Watershed Protection Alliance (FL-LOWPA) funding. Mechanical harvesting in Oneida Lake is scheduled for the summer of 2002, but no definitive dates have been set. Oswego County Environmental Management Council (EMC) has produced several informative handouts including a small water chestnut alert card and a two-sided water chestnut alert fact sheet to educate the public on water chestnut.

Annual harvesting is conducted in Ox Creek, a tributary of the Oswego River. Once noted as a top location for bass fishing, since 1990 it has been so heavily infested with water chestnut that the waterway becomes unnavigable each summer. Mechanical harvesting is performed each year, but is difficult to do since the creek is filled with submerged stumps and debris. Unfortunately, the current goal of the harvesting in Ox Creek is only to clear a navigation pathway to allow recreational activities to resume, not to eliminate the water chestnut population.

Wayne County: Water chestnut was discovered in the southern end of Sodus Bay in the late 1980s. Hand-pulling programs were organized by the Boy Scouts of America to help keep the waterway navigable by canoe (non-motorized area). Over the past 5 to 10 years, water chestnut populations have increased and been established north of Bay Bridge. Mechanicals harvesting, along with hand-pulling sessions, have been organized by the Wayne County SWCD with continued support from the Boy Scouts and concerned lakeshore residents. In July 2002, 42 tons of water chestnut were mechanically harvested from Sodus Bay with an additional 1.5 tons harvested via hand pulling. In the summer of 2002, a new infestation site was discovered in East Bay. East Bay is located east of Sodus Bay and before Port Bay. Coincidentally, this was the first summer that the Bay had been opened to traffic from Lake Ontario. The population covered an area 10 feet long x 15 feet wide. Plans are currently being made to remove the water chestnut from

East Bay. The spread of water chestnut to these bays is said to have been by "hitchhikers." (As per a 7/02 phone conversation with Tiffany Boas, Wayne County SWCD)

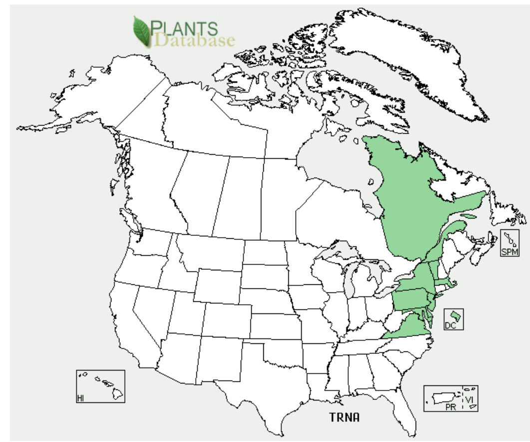
Future Funding and Continued Efforts in the Central New York Region

Madison, Onondaga and Oswego Counties, in conjunction with FL-LOWPA, were awarded a $25,000 grant from the National Fish and Wildlife Foundation towards public education and organized harvesting of water chestnut in Oneida Lake and the Three Rivers area. As part of the grant requirement, multiple-year goals were established (see Attachments 2 and 3). Educational brochures and pamphlets were prepared and public hand-pulling sessions were organized with a portion of the grant money to encourage public support and awareness. The majority of this grant money is being applied towards mechanical harvesting within Oneida Lake and the Oneida River area.

Madison, Onondaga and Oswego Counties, with FL-LOWPA, plan to re-apply for the annual grant opportunity with the National Fish and Wildlife Foundation to continue funding their public education and outreach programs and expand mechanical harvesting and hand-pulling programs to newly infested and continually infested waterways throughout Onondaga and Oswego Counties. As a guideline, the three counties will work together and continue to follow the multiple-year goals (see Attachments 2 and 3) developed to help control and eradicate water chestnut from Central New York. However, with this minimal level of grant funding plus the provided match, preventing the further spread of water chestnut into Oneida Lake will remain the primary objective in the short-term.

In addition, as part of the continuing control measures against water chestnut, Dr. Bernd Blossey (Cornell University) is working to find a biological control agent for non-indigenous aquatic plants, including water chestnut, with funds provided through Congressman James Walsh.

To fully eliminate water chestnut from Oswego and Onondaga Counties and keep it from spreading into other areas of CNY will take persistence, determination and cooperation from lakeshore communities, private organizations, and county, state and federal agencies. With the continued support from private groups and organizations within the region, Madison, Onondaga and Oswego Counties hope to see a surge of public interest and participation in the control efforts of water chestnut. An increase in organized hand-pulling sessions will not only help to control the noxious weed populations, but spark community involvement and education. An increase in funds allocated towards mechanical harvesting will also help to eradicate dense populations of water chestnut in a timely manner. ***Above what is currently available, the need for funding and harvesting equipment to address the water chestnut problem is substantial. It would appear that a federal interest, especially in terms of funding, is essential to enable adequate control of water chestnut in the Central New York area given the current lack of a biological or chemical remedy. While research is underway to identify biological control measures, whether chemical treatment is a possibility must be determined soon.*** It is through a combination of all these efforts that water chestnut will be eradicated from Central New York, improving recreational activities and enjoyment of our waterways.



States and provinces where *Trapa natans* is found.
Image taken from USDA NRCS Plants Database.
http://plants.usda.gov/core/profile?symbol=TRNA