Host Specificity and Environmental Impact of the Weevil Hylobius transversovittatus, a Biological Control Agent of Purple Loosestrife (Lythrum salicaria)

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Host Specificity and Environmental Impact of the Weevil *Hylobius transversovittatus*, a Biological Control Agent of Purple Loosestrife (*Lythrum salicaria*)[1]

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Abstract. **Introduction of purple loosestrife into North America and its spread into wetlands has led to the degradation of these important habitats for wildlife. Conventional control efforts are unsuccessful in providing long-term control. A classical biological control program offers the best chance for reducing the numbers of this invasive plant and improving regeneration of the native flora and fauna. European studies demonstrated that the root boring weevil *Hylobius transversovittatus* is highly host specific to the target weed. Attack of two test plant species (winged lythrum and swamp loosestrife) during host range screening was most likely due to artificial test conditions. An environmental assessment of the potential effects of the release of the purple loosestrife borer in North America indicated that benefits outweigh any potential negative impact. Therefore its field release was approved in 1992. Nomenclature: Purple loosestrife borer, *Hylobius transversovittatus* Goeze; purple loosestrife, *Lythrum salicaria* L. #[3] LYTSA; winged lythrum, *Lythrum alatum* Pursh # LYTAL; swamp loosestrife, *Decodon verticillatus* (L.) Ell. # DEOVE.**

Additional index words. **Biological control, purple loosestrife borer, wetlands, LYTSA, LYTAL, DEOVE.**

INTRODUCTION

Purple loosestrife is an exotic perennial from Eurasia invading and degrading the quality of North American wetland habitats over much of the temperate parts of the United States and Canada (28, 29). No effective method is available to control purple loosestrife except where it occurs in small localized stands. Control techniques include water level manipulation, mowing or cutting, burning, and herbicide application. These techniques successfully eliminate small and young stands but are costly and require long-term maintenance, and nonselective herbicides negatively affect the native flora. The most commonly used herbicides against purple loosestrife are glyphosate [*N*-(phosphonomethyl)glycine], 2,4-D [(2,4-dichlorophenoxy)acetic acid], and, on an experimental basis, triclopyr {[(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid}. These are nonspecific herbicides and when used on areas with extensive purple loosestrife infestations have had detrimental effects on nontarget wetland plants (27).

In North America, purple loosestrife has attracted few polyphagous herbivores which have an important impact on the plant (17). In contrast, European purple loosestrife plants are severely damaged by several specialized phytophagous insects (5, 6). Present efforts to control purple loosestrife center about the importation of phytophagous insects from the plant's native range, a classical biological weed control program. By filling empty niches on purple loosestrife we hope to reduce the competitive advantage of the plant (8, 24). Subsequent introduction and impact of biological control agents attacking roots, leaves, and flowers should favor the currently suppressed native vegetation.

Skepticism concerning safety and effectiveness of exotic introductions for weed control remains prevalent. However, during the past 100 yr some 200 control agents have been released against 114 weed species worldwide (19). No negative effects, i.e., no host shifts severely damaging nontarget plants, have been reported (9). The demonstrated restriction of a biological control agent to the target weed is an essential prerequisite for releasing an agent into a new environment (21, 23).

Purple loosestrife is an erect, herbaceous perennial wetland plant, growing in a wide range of habitats (28). Mature plants can grow to 2 m and produce more than two million seeds a year. High temperatures and open moist soils are required for successful germination. The storage organ is a laterally branching rootstock from which annual shoots emerge. Purple loosestrife is often found in monospecific stands in North America but occurs only in small, scattered populations in its native range (4, 18, 29).

The mainly nocturnal purple loosestrife borer is the only species in the genus *Hylobius* known to feed on a herbaceous plant. All other European or North American species live on conifers, and several are important forest pests (15). The purple loosestrife borer occurs throughout Europe, and in the Caucasus and Siberia (20, 26). Adults consume foliage and stem tissue. Eggs are laid into the soil close to the host plant or into a stem. Larvae hatching from eggs deposited in soil feed on roothairs and rootlets. Those hatching in the shoot mine the pith before moving below ground. Young larvae preferably feed on the cortex and enter the root when they reach young soft tissue. The mines are filled with light-brown packed frass. Mature larvae form pupation chambers in the upper parts of the root and prepare exit windows for the emerging adults. Adult weevil length varies between 5 and 15 mm depending on food quality (5).

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[3]Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Revised 1989. Available from WSSA, 1508 West University Ave., Champaign, IL 61821-3133.

Impact on plant performance is dependent on number of larvae per root and root size (4). Smaller roots, only a few years old, can be completely devastated by feeding of one or two larvae. Larval feeding reduces above- and belowground plant biomass and seed output, and increases plant mortality (4). Adults have a good host-finding capacity, demonstrated by their colonization of newly established purple loosestrife populations (5).

Laboratory tests have demonstrated that the purple loosestrife borer is a potential host of entomopathogenic nematodes, but field populations in Europe were never found attacked. Therefore, entomopathogenic nematodes should not lower the expected impact of the weevil on purple loosestrife (7).

This paper presents an investigation of the host specificity of the purple loosestrife borer and an assessment of the environmental impact of a release of the weevil into North American wetlands.

MATERIALS AND METHODS

Forty-eight plant species were approved for host specificity screening tests by the Technical Advisory Group for the Introduction of Biological Control Agents of Weeds (TAG)[4]. A complete list is given in Blossey et al. (8). Host specificity testing was split between the International Institute of Biological Control in Europe and the quarantine facility at Virginia Polytechnic Institute & State University (VPI&SU), Blacksburg, VA. Species difficult to grow under northern German climate or where more information was needed were tested in quarantine (8, 22).

Adult feeding and oviposition tests. Purple loosestrife roots infested with weevil larvae were field collected in Germany and Scandinavia between 1986 and 1988. To obtain parental stock, roots were kept in the laboratory until adults emerged. Screening tests with adult beetles obtained from the rearing were carried out in a greenhouse at Christian-Albrechts-University (CAU), Kiel, northern Germany under natural photoperiod and fluctuating temperatures (10 to 30 C). European test plants were obtained from natural populations. North American test plant species were grown from seeds, roots, or tubers shipped from the U.S. All test plants were grown in commercial potting soil in 10-cm-diameter clay pots. Most plants were grown outdoors to obtain healthy specimens. Plants with a southern distribution were grown in the greenhouse.

Well-developed potted test plants in random combinations of five to seven species were offered in a multiple-choice test (without purple loosestrife) in screened cages of 40 by 40 by 60 cm. Only crepe myrtle (*Lagerstroemia indica* L.) and pomegranate (*Punica granatum* L.) were offered as unrooted cut shoots collected from ornamental trees grown in the Botanical Gardens at CAU. The control with adults caged exclusively on unrooted cut shoots of purple loosestrife was run simultaneously. Stems were pushed through florist's foam into a water-filled container. This method was successfully used in mass-rearing the weevil on purple loosestrife and provided excellent results. Females readily accepted the moistened foam as a soil substitute. The oviposition pattern of the purple loosestrife borer varied throughout the season (5). The separate control provided the necessary baseline data to compare number of eggs produced in the screening experiments. Five replicates for each test plant species and the control were conducted with three pairs of adults per cage.

After 1 wk, test plants were removed from cages and adult feeding recorded in three damage classes. A few feeding marks on stems or leaves were called occasional nibbling. If an obvious amount of leaf foliage had been eaten it was recorded as slight to moderate feeding. Normal feeding was the removal of foliage on a test plant similar in amount to that on the purple loosestrife control plants. Shoots were dissected and soil around the roots removed to a depth of 5 cm to check for eggs. Weevils were allowed to feed on purple loosestrife for 1 wk after they had been used in the test to insure oviposition capability. Experiments were conducted throughout the weevil's oviposition period between May and August.

In an additional no-choice experiment, two pairs of newly emerged overwintered weevils were caged on cut shoots of swamp loosestrife (*Decodon verticillatus* L.) and winged lythrum (*Lythrum alatum* Pursh.). Weevils used in this test were not allowed to feed on purple loosestrife prior to the experiment. Five replicates per test plant species were monitored for feeding, survival, and oviposition.

Larval transfer tests. Vigorous newly hatched larvae were placed in the soil close to the root of test plants to determine if they were able to successfully complete development. Larvae were transferred with a small hairbrush. Five replicates were conducted, each using two larvae per test plant species. Due to the limited number of plants, only one replicate was possible with *Rotala ramosior* (L.) Koehne and four with *Zizania aquatica* L. Pomegranate, and crepe myrtle were not tested in this particular experiment because whole plants were not available. All test plants were kept for 3 mo and then dissected to check for presence or feeding damage of larvae. Live larvae were transferred to uninfested plants of the same species to follow their development until the period of adult emergence the following year.

Field tests. Five swamp loosestrife and five winged lythrum plants grown in pots were dug into the ground within an established field population of purple loosestrife in May 1990 at Lembruch, Lower Saxony, Germany. The plants at this locality were highly infested with purple loosestrife borer larvae. Plants left at the site until September were re-collected and taken to the laboratory for dissection.

In 1991, permission was granted to release the purple loosestrife borer into field cages in North America. At a New York field site, potted plants of swamp loosestrife (15 plants), winged lythrum (6 plants), and purple loosestrife (15 plants) were sunk into the ground inside a 2-m^3 screen field cage. Plants were grown in 20-cm-diameter clay plots filled with a commer-

[4]Abbreviations: TAG, Technical Advisory Group for the Introduction of Biol. Control Agents of Weeds; CAU, Christian-Albrechts Univ., Kiel, 2300 Kiel, Germany; VPI&SU, Virginia Polytechnic Inst. and State Univ., Blacksburg, VA.

cial potting soil mixture (Sunshine mix, no fertilizer added). Pots were arranged randomly and all other vegetation inside the cages was removed. Twenty-five 1-yr-old ovipositing females were released into the cage in August. Plants were re-collected in December and dissected for larval attack.

Survey questionnaire. In November 1990 a progress report and a questionnaire concerning the potential impact of this program were sent to representatives in 32 states in the temperate part of the U.S. Two questionnaires were sent to each state, one to the Department of Agriculture and another to the Department of Natural Resources, Conservation, Fish and Game, or Wildlife. The questionnaire asked for the occurrence, special concerns (rare or endangered), and ecological importance of swamp loosestrife and winged lythrum in each state. The questionnaire also asked whether respondents would favor a release of biological control agents against purple loosestrife over a potential negative impact on swamp loosestrife and winged lythrum. The intent of the survey was to obtain an evaluation of the control program based on the opinion of individuals directly involved in wetland ecology and conservation.

Table 1. Plants attacked in multiple-choice (without regular host plant) adult feeding, oviposition, or no-choice larval transfer tests with the purple loosestrife borer[a].

Test plant species	Adult feeding[b]	Oviposition	Larval development
		no. eggs	%
Lythrum salicaria L.	++	70	60
L. alatum Pursh.	+	35	29
L. californicum Torr. & Gray	(+)	—	—
L. hyssopifolia L.	+	5	—
Decodon verticillatus (L.) Ell.	+	—	50
Ammania auriculata Willd.	(+)	—	—
Gaura parviflora Dougl.	—	1	—
Rumex crispus L.	(+)	—	—
Triticum aestivum L. 'Blue Boy'	(+)	—	—
Beta vulgaris L. 'Golden Tankard'	—	1	—

[a]Dashes indicate that no feeding, oviposition, or larval development occurred.

[b]++ indicates normal feeding, + indicates slight to moderate feeding, and (+) indicates occasional nibbling.

RESULTS AND DISCUSSION

Adult feeding and oviposition tests. Normal feeding was restricted to purple loosestrife, slight to moderate feeding occurred on winged lythrum, swamp loosestrife, and hyssop lythrum (*L. hyssopifolia* L., #LYTHY) and some nibbling was observed on four other plant species (Table 1). The highest rate of oviposition occurred on purple loosestrife (70 eggs) and winged lythrum (35 eggs). Five eggs were found on hyssop lythrum and one egg each on *Gaura parviflora* Dougl. and sugarbeet (*Beta vulgaris* L.). Eggs on the latter two plant species were found on the soil surface and are most likely laboratory artifacts.

When pairs of overwintered weevils were caged on winged lythrum, females produced an average of 0.5 eggs per day over a 2-mo period. Only two eggs were found in cages with swamp loosestrife during the entire period. Oviposition rate on the control purple loosestrife averaged about three eggs per day per female (Figure 1).

Larval transfer tests. First instar larvae transferred to potted test plants developed into adults only on winged lythrum (29%) and swamp loosestrife (50%) (Table 1). Of the larvae transferred to purple loosestrife controls, 60% completed development successfully. All other test plant species remained unattacked.

Field tests. Potted swamp loosestrife and winged lythrum plants exposed to ovipositing females of the purple loosestrife borer at Lembruch remained unattacked. No signs of adult or larval feeding were found when the plants were collected in the fall and dissected. In contrast, roots of adjacent purple loosestrife plants were attacked by an average of three larvae per root.

Average number of larvae per pot in the cage at the field site in New York was as follows: purple loosestrife, 18.3; winged lythrum, 3; and swamp loosestrife, 4.5. Thus the rate of oviposition on the two potted native Lythraceae species was considerably lower compared to purple loosestrife; i.e., attaining only 16 and 25% on winged lythrum and swamp loosestrife, respectively, even under extreme overcrowding.

In Europe, 13 species of *Lythrum* occur within the general distribution area of the purple loosestrife borer. The insect fauna of Europe is well documented and lists purple loosestrife as the sole host for this weevil. Specialization of this species (all other members of the genus *Hylobius* live on conifers) strongly indicates that it has no tendency to extend its host range. Even in areas with high attack rates of purple loosestrife along lake margins in Scandinavia, there was no attack on adjacent plants (4).

Screening results demonstrated that the purple loosestrife borer is highly specific to purple loosestrife. Limited feeding and/or oviposition on winged lythrum and swamp loosestrife, in laboratory screening tests, indicates their potential as hosts. However, insects in confined laboratory feeding tests often show broader host ranges than in the field (11). Given a choice, as in

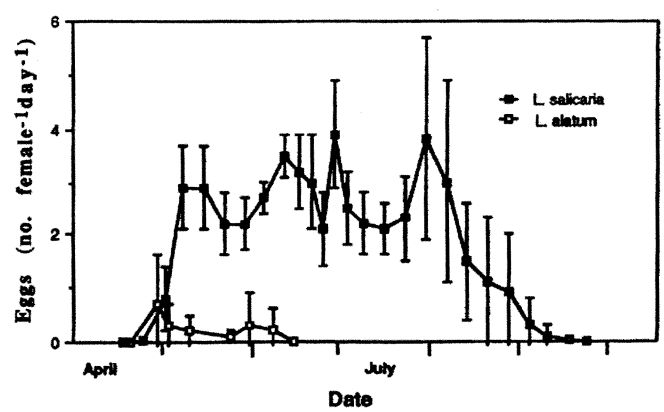

Figure 1. Oviposition of *H. transversovittatus* on unrooted cut shoots of *Lythrum salicaria* and *L. alatum* during 1990. Values are means of 5 replicates ± SD.

the field tests in Europe, the weevil did not choose winged lythrum nor swamp loosestrife for oviposition.

In quarantine the weevil oviposited and fed on cut unrooted shoots of swamp loosestrife and winged lythrum but not on potted test plants (22). Alternating biweekly potted purple loosestrife and swamp loosestrife in a no-choice situation substantially reduced the oviposition rate of the purple loosestrife borer onto swamp loosestrife plants (22). Females that had fed for 2 wk on purple loosestrife most certainly had developing eggs in their oviduct if transferred to swamp loosestrife. These eggs were then laid into the soil. Under such artificial conditions, number of eggs laid, although significantly different for the two plant species, was still higher than in European tests.

Swamp loosestrife and winged lythrum are vulnerable to a reduced rate of attack in no-choice situations. However, in the European no-choice starvation and oviposition tests in confinement, a reduced oviposition rate and life span were observed. Furthermore, in nature swamp loosestrife tends to grow in continually flooded places. Both observations reduce the probability for these species to become field hosts of the purple loosestrife borer since larvae cannot develop in permanently flooded roots. However, they are able to survive long periods of submergence in a state of arrested development (3).

Survey questionnaire. We received 44 responses (67% return) and except for New York at least one agency responded in each state. We received an additional response by West Virginia, which originally was not covered by our survey, and included it in our evaluation (Table 2). A majority of states reported the occurrence of swamp loosestrife (62%) and winged lythrum (72%). Swamp loosestrife was listed by four states (12%) as a species of special concern and was noted by nine (28%) as having important ecological attributes. The more widely distributed winged lythrum was considered of special concern by three (9%) states and of ecological importance by four (12%) states. The primary ecological importance of both plant species was their occurrence in unique wetland communities (fens and bogs). Swamp loosestrife has an additional attribute as being the sole host plant for the endangered moth (*Papaipema sulphurate* Bird)[5]. Neither swamp loosestrife nor winged lythrum occur on the list of U.S. endangered and threatened plant species (1). Concerning swamp loosestrife, 13 states favored the release of biocontrol candidates, seven states did not. In five states the Department of Natural Resources did not favor a release whereas the Department of Agriculture favored the release of exotic organisms. Six states responding to the questionnaire did not address this particular question. Concerning winged lythrum, 17 states favored a release and five states did not. An additional five states responded to the questionnaire but did not address the particular question about release of biocontrol agents. In another five states the Department of Natural Resources did not favor a release whereas the Department of Agriculture favored the release of biocontrol agents against purple loosestrife.

The most common concern of negative respondents was lack of sufficient information to appropriately evaluate danger to native plants. The other commonly expressed concern was fear of introducing additional exotic species into the environment which could become a problem similar to purple loosestrife, gypsy moth, or the European starling.

The importance of a plant species is difficult to evaluate. The U.S. Fish and Wildlife Service considers swamp loosestrife undesirable because it becomes locally dominant in waterfowl habitats (30). Neither it nor winged lythrum is listed as important to wildlife (25). We reviewed the more than a quarter of a million examination cards of bird stomach contents archived at the Patuxent Wildlife Research Center, U.S. Fish and Wildlife Service, Patuxent River, MD. Swamp loosestrife was noted on only 27 records with usually less than 10 seeds per record. Winged lythrum was never noted. Also, swamp loosestrife and winged lythrum have never been listed as important by horticulturists or agriculturists. Historically, winged lythrum was used to treat sores and ulcers (3), but the species was not mentioned in a recent listing of medicinal herbs (12).

Both swamp loosestrife and winged lythrum are native members of North American wetlands, an important ecological community. It is this community that our biological control project is targeted to protect. Both plant species are at risk of being eliminated by competition from purple loosestrife in areas where they co-occur[6]. Although swamp loosestrife is often associated with purple loosestrife, swamp loosestrife is more shade and water tolerant than purple loosestrife, and is usually found in openings or watery edges of cattail marshes, deadwood swamps, openings in cypress swamps, sphagnum bogs, and undisturbed low-lying lake margins (13). Purple loosestrife grows poorly in permanently flooded habitats or in shaded areas. Also unlike swamp loosestrife, purple loosestrife favors disturbed habitats (12). The two plants overlap in their North American geographic distribution from Nova Scotia and southern Ontario to Minnesota, south to Missouri and Virginia. Swamp loosestrife continues along the southeastern coast to Florida and the Gulf Coast States to Texas, outside the range of purple loosestrife (10, 16).

Winged lythrum primarily occupies two types of plant communities: wet meadows and mesic prairies (14). Although winged lythrum is more mesophytic than purple loosestrife, the two species often occur sympatrically in moist soil habitats north of the 35th parallel (2). Unlike purple loosestrife, winged lythrum is a relatively obscure component of the community. Winged lythrum is widely distributed outside the range of purple loosestrife, occurring throughout the southeastern states from North Carolina into Texas and the southern Midwest (16).

Results of host specificity screening demonstrated that swamp loosestrife and winged lythrum, as well as other members of wetland communities, should be safe from attack by the purple loosestrife borer. The slight probability of occasional feeding on a few native species has to be carefully weighed against the

[5]Personal communication, D. French, Asst. Dir., Massachusetts Natural Heritage and Endangered Species, Boston, MA.

[6]Personal communication, N. A. Anderson, Grad. Asst., Dep. Hortic. Sci., Univ. Minnesota, St. Paul, MN; and personal communication, C. Eckert, Asst. Prof., Dep. Biol., Queen's Univ., Kingston, Ontario, Canada.

Table 2. Responses to survey questionnaire for occurrence, special concerns, and ecological importance of winged lythrum and swamp loosestrife from State Departments of Agriculture (AG) and State Departments of Natural Resources, Conservation, and/or Fish and Wildlife (NR). The favorability of a release of control agents against purple loosestrife in light of the status of both plants in each state is included[a].

		Occurrence in state		Special concern		Ecological importance		Release favored	
State	Agency	Winged lythrum	Swamp loose-strife	Winged lythrum	Swamp loose-strife	Winged lythrum	Swamp loosestrife	Winged lythrum	Swamp loose-strife
California	AG	—	—	—	—	—	—	Yes	Yes
Colorado	AG	+	—	—	*[a]	—	*	Yes	*
Connecticut	AG	+	+	—	—	—	—	No	No
	NR	+	+	—	—	—	—	Yes	Yes
Delaware	AG	—	+	—	—	—	Unique habitat component	Yes	No
	NR	—	+	*	—	*	—	Yes	Yes
Idaho	AG	+	—	—	—	—	—	Yes	Yes
	NR	—	—	*	*	*	*	*	*
Illinois	NR	+	+	—	—	—	Unique habitat component	Yes	Yes
Indiana	NR	+	+	—	—	—	—	Yes	Yes
Iowa	AG	+	+	—	Endangered	—	—	Yes	Yes
	NR	+	+	—	Endangered	—	—	No	No
Kansas	NR	+	—	—	*	*	Potential medicinal plant	*	*
Maine	AG	—	+	—	—	—	—	No	No
	NR	—	+	—	—	—	—	No	No
Maryland	AG	+	+	Rare	—	—	—	Yes	Yes
	NR	+	+	Rare	—	Unique genetic population	Increased wetland quality	No	No
Massachusetts	NR	+	+	—	—	—	Host of a threatened moth	*	Yes
Michigan	AG	+	+	—	—	—	—	Yes	Yes
	NR	+	+	—	—	Important wetland plant	Bog mat pioneer	No	No
Minnesota	AG	+	+	—	Rare	—	—	Yes	Yes
	NR	+	+	—	Rare	—	—	Yes	Yes
Missouri	NR	+	+	—	Endangered	Unique wetland component	Disjunct population	Yes	No
Montana	AG	—	—	*	—	—	*	*	*
Nebraska	AG	+	—	—	*	—	*	Yes	*
	NR	+	—	—	—	Wet prairie component	Wetland component	No	No
Nevada	NR	—	—	—	—	—	—	No	No
New Hampshire	AG	+	+	—	—	—	Bog community component	Yes	Yes
	NR	+	+	—	—	—	Bog community component	Yes	No
New Jersey	AG	+	+	—	—	—	—	Yes	Yes
New York								No response	
North Dakota	AG	+	—	—	—	—	—	*	*
Ohio	AG	+	+	—	—	Ornamental	Nectar & pollen source	No	No
	NR	—	+	—	—	Prairie fens community	Bog community component	No	No
Oregon	AG	—	—	—	—	*	*	*	*
Pennsylvania	AG	+	+	—	—	—	—	Yes	Yes
Rhode Island	NR	+	+	—	—	—	Host of threatened moth	Yes	Yes
South Dakota	AG	+	—	—	*	—	*	Yes	*
Vermont	NR	—	+	—	—	—	Wetland component	Yes	Yes
Virginia	NR	+	+	Rare	—	Wetland indicator	Wetland indicator	No	No
Washington	AG	—	—	—	—	*	*	*	*
	NR	—	—	—	—	—	—	Yes	Yes
West Virginia	NR	+	+	Rare	Rare	—	—	No	No
Wisconsin	NR	+	+	—	—	—	—	Yes	Yes
Wyoming	NR	+	—	—	—	—	—	Yes	Yes

[a]* indicates that agency responded to questionnaire but did not address the specific question.

possibility of replacement of large parts of native North American wetland flora by monospecific stands of purple loosestrife.

The release of the purple loosestrife borer was approved by the TAG, and in summer 1992 the weevil and two additional control agents attacking the leaves (8) were introduced into field nurseries in North America. Their combined effect should significantly increase stress on purple loosestrife and reduce its competitive ability.

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LITERATURE CITED

1. Anonymous. 1989. U.S. Fish and Wildlife Service. Endangered & Threatened Wildlife and Plants. U.S. Gov. Printing Off., Washington, D.C. 34 pp.
2. Anderson, N. A. and P. D. Ascher. 1993. Style morph frequencies in Minnesota populations of *Lythrum* (Lythraceae). I. Distylous *L. alatum* Pursh. Plant Cell Incompatibility Newsl. 25: (in press).
3. Baillon, H. 1880. The Natural History of Plants. Vol. VI. L. Reeve & Co., London.
4. Blossey, B. 1991. Biology, ecology, host specificity, and impact of *Galerucella calmariensis* L., *G. pusilla* Duft. (Coleoptera: Chrysomelidae) and *Hylobius transversovittatus* Goeze (Coleotera: Curculionidae) on their host plant *Lythrum salicaria* L. (purple loosestrife). PhD Thesis, Zool. Inst., Christian Albrechts Univ., Kiel, Germany. 115 pp. (in German).
5. Blossey, B. 1993. Herbivory below ground and biological weed control: life history of a root-boring weevil on purple loosestrife. Oecologia 94:380–387.
6. Blossey, B. 1993. Impact of *Galerucella pusilla* Duft. and *G. calmariensis* L. (Coleoptera: Chrysomelidae) on field populations of purple loosestrife (*Lythrum salicaria* L.). Pages 000–000 *in* E. S. Delfosse and R. R. Scott, eds. Proc. VIII Int. Symp. Biol. Control of Weeds. DSIR/CSIRO, Melbourne (in press).
7. Blossey, B. and R. U. Ehlers. 1991. Entomopathogenic nematodes (*Heterorhabditis spp.* and *Steinernema anomali*) as potential antagonists of the biological weed control agent *Hylobius transversovittatus* Goeze (Coleoptera: Curculionidae). J. Invertebr. Pathol. 58:453–454.
8. Blossey, B., D. Schroeder, S. D. Hight, and R. A. Malecki. 1993. Host specificity and environmental impact of two leaf beetles for the biological control of purple loosestrife (*Lythrum salicaria*). Weed Sci. (In press).
9. Crawley, M. J. 1989. The successes and failures of weed biocontrol using insects. Biocontrol News and Info. 19:213–223.
10. Cronquist, A. 1981. An Integrated System of Classification of Flowering Plants. Columbia Univ. Press, New York.
11. Cullen, J. M. 1990. Current problems in host specificity screening. Pages 27–36 *in* E. S. Delfosse, ed. Proc. VII Int. Symp. Biol. Control of Weeds. Ist. Sper. Patol. Veg. (MAF), Rome.
12. Duke, J. A. 1985. CRC Handbook of Medicinal Herbs. CRC Press, Boca Raton, FL.
13. Eckert, C. and S. C. H. Barrett. 1992. Stochastic loss of style morphs from populations of tristylous *Lythrum salicaria* and *Decodon verticillatus* (Lythraceae). Evolution 46:1014–1029.
14. Eggers, S. D. and D. M. Reed. 1987. Wetland plants and plant communities of Minnesota and Wisconsin. U.S. Army Corps of Engineers, St. Paul.
15. Eidmann, H. H. 1974. *Hylobius* Schönh. Pages 275–293 *in* W. Schwenke, ed. Die Forstschädlinge Europas, 2. Band, Paul Parey, Hamburg, Berlin.
16. Gleason, H. A. and A. Cronquist. 1963. Manual of Vascular Plants of Northeastern United States and Adjacent Canada. D. Van Nostrand Co., New York.
17. Hight, S. D. 1990. Available feeding niches in populations of *Lythrum salicaria* L. (purple loosestrife) in the Northeastern United States. Pages 269–278 *in* E. S. Delfosse, ed. Proc. VII Symp. Biol. Control of Weeds. Ist. Sper. Patol. Veg. (MAF), Rome.
18. Hight, S. D. and J. J. Drea, Jr. 1991. Prospects for a classical biological control project against purple loosestrife (*Lythrum salicaria* L.). Natural Areas J. 11:151–157.
19. Julien, M. H. 1992. Biological control of weeds. A World Catalogue of Agents and Their Target Weeds. 3rd ed. CAB International, Wallingford, UK.
20. Kippenberg, H. 1983. 115. Gattung: *Hylobius.* Pages 125–126 *in* H. K. Freude, W. Harde, and G. A. Lohse, eds. Die Käfer Mitteleuropas, Band 11. Goecke und Evers, Krefeld, Germany.
21. Klingman, D. L. and J. R. Coulson. 1982. Guidelines for introducing foreign organisms into the United States for the biological control of weeds. Weed Sci. 20:661–667.
22. Kok, L. T., T. J. McAvoy, R. A. Malecki, S. D. Hight, J. J. Drea Jr., and J. R. Coulson. 1992. Host specificity tests of *Hylobius transversovittatus* Goeze (Coleoptera: Curculionidae), a potential biological control agent of purple loosestrife, *Lythrum salicaria* L. (Lythraceae). Biol. Control 2:1–8.
23. Lima, P. J. 1990. United States Department of Agriculture (USDA) safeguards for introducing natural enemies for biological control of weeds. Pages 109–115 *in* E. S. Delfosse, ed. Proc. VII Int. Symp. Biol. Control of Weeds. Ist. Sper. Patol. Veg. (MAF), Rome.
24. Malecki, R. A., B. Blossey, S. D. Hight, D. Schroeder, L. T. Kok, and J. R. Coulson. 1993. Biological control of purple loosestrife. Bioscience 43:680–686.
25. Martin, A. C., H. S. Zim, and A. L. Nelson. 1951. American Wildlife and Plants. McGraw-Hill Book Co., New York.
26. Palmén, E. 1940. Zur Biologie und nordeuropäischen Verbreitung von *Hylobius transversovittatus* Steph. (Coleoptera: Curculionidae). Ann. Entomol. Fenn. 6:129–140.
27. Skinner, L. C., W. J. Rendall, and E. L. Fuge. 1993. Minnesota's purple loosestrife program: history, findings and management recommendations. Minnesota Dep. Natural Resources, Special Publ. 145. Minnesota Dep. Natural Resources, St. Paul, MN.
28. Stuckey, R. L. 1980. Distributional history of *Lythrum salicaria* (purple loosestrife) in North America. Bartonia 47:3–20.
29. Thompson, D. Q., R. L. Stuckey, and E. B. Thompson. 1987. Spread, impact, and control of purple loosestrife (*Lythrum salicaria*) in North American wetlands. U.S. Fish and Wildl. Serv., Fish and Wildl. Res. 2. 55 pp.
30. Uhler, F. M. 1944. Control of undesirable plants in waterfowl habitats. Trans. North American Wildl. Conf. 9:295–303.