74 *Lythrum salicaria* L., Purple Loosestrife (*Lythraceae*)

C.J. Lindgren, J. Corrigan and R.A. De Clerck-Floate

Pest Status

Purple loosestrife, *Lythrum salicaria* L., is a Eurasian wetland perennial, likely introduced to North America in the early 1800s (Thompson *et al.*, 1987). Cultivated varieties of *L. salicaria*, developed as early as 1937 (Harp and Collicut, 1983), have been widely used across North America by gardeners and landscapers and have further contributed to its spread (Ottenbreit, 1991; Lindgren and Clay, 1993). *L. salicaria* is capable of forming continuous stands that can displace native vegetation, which provides food, cover and breeding areas for wildlife. Thompson *et al.* (1987) estimated that controlling this plant across the invaded wetlands of 19 American states would cost US$45.9 million per year.

L. salicaria has invaded every Canadian province (White *et al.*, 1993). In British Columbia, it can be found along the Fraser River, Iona Island, Westham Island, Vancouver Island, Jericho Park (Vancouver), the Ladner Marsh, the Okanagan Valley, Chilliwack and Nelson (Myers and Denoth, 1999). In Alberta, the first infestation was reported in 1990 near Medicine Hat. Ali and Verbeek (1999) reported more than 315,000 plants in 1994 and infestations in as many as 185 individual wetlands in 1999. In Saskatchewan, *L. salicaria* is found mostly in urban settings, e.g. Saskatoon, Moose Jaw, Regina, Swift Current and Yorkton (A. Salzl, Saskatoon, 1999, personal communication). In Manitoba, *L. salicaria* was first reported in 1896, and has since spread to every major river system in southern Manitoba, with large infestations in the south basins of lakes Winnipeg and Manitoba. In Ontario, *L. salicaria* has a long history of residency (100+ years), and many extensive populations are established south of the 49th parallel (White *et al.*, 1993). In Quebec, large populations exist in the Eastern Townships, and along the lower Ottawa and St Lawrence River valleys (White *et al.*, 1993). Although *L. salicaria* has been present in Quebec since the 1800s, farmers became concerned in 1949 when loosestrife began replacing forage crops in riparian pastures (Templeton and Stewart, 1999). In New Brunswick, *L. salicaria* is a concern in most of the lower marsh in the Saint John flood plain. Prior to the 1960s, botanical surveys revealed none in this region (J. Wile, Amherst, 1999, personal communication). In Nova Scotia, *L. salicaria* is widespread, with large infestations reported on Cape Breton and on the mainland (G. Sampson, Truro, 1999, personal communication). In Prince Edward Island, *L. salicaria* can be found throughout the province, with larger infestations found around larger towns and villages. It is also present in salt marshes on the upper Hillsborough River (T. Duffy, Charlottetown, 2000, personal communication). In Newfoundland, *L. salicaria* is present in western, central and eastern regions of the island. However, its distribution is patchy and it is not common anywhere. *L. salicaria* has not been recorded from Labrador (P. Dixon, St John's, 2000, personal communication).

L. salicaria, including all cultivated varieties, has been designated a noxious weed in Prince Edward Island (1991), Alberta

(1992) and Manitoba (1996). Provincial working groups formed to combat this weed include the Alberta Purple Loosestrife Eradication Program, Saskatchewan Purple Loosestrife Eradication Project, the Manitoba Purple Loosestrife Project and Project Purple in Ontario.

Background

Malecki *et al.* (1993) stated: 'No effective method is available to control *L. salicaria*, except where it occurs in small localized stands and can be intensively managed.' Control methods attempted include water-level manipulation, physical removal, mowing, burning and herbicide application, but these are costly, localized and short-term. Biological control represents the only option, given the geographical and temporal scales of the problem (Malecki *et al.*, 1993).

Biological Control Agents

Insects

Diehl *et al.* (1997) collected 51 species of resident herbivorous insects on *L. salicaria* in Manitoba, but concluded that they are not effective in reducing its density there. Based on the history of the spread of this plant across Canada (White *et al.*, 1993), we believe this conclusion applies nationally.

In Europe, over 100 species of phytophagous insects have been associated with *L. salicaria* (Batra *et al.*, 1986). De Clerck-Floate (1992) recommended that the European root-mining weevil, *Hylobius transversovittatus* (Goeze), and the leaf beetles, *Galerucella calmariensis* L. and *Galerucella pusilla* Duftschmid, be released against *L. salicaria*. These agents have narrow host ranges, climatic origins compatible with those of Canada, and potential for causing extensive damage to *L. salicaria*. These three species were approved for release in 1992.[1] Two other European weevils, *Nanophyes marmoratus* Goeze and *Nanophyes brevis* Boheman, were approved for release in 1994. Releases of four of the agents were made in Canada from 1992 to 1999. European screening prior to agent importation revealed populations of *N. brevis* to be infected with an unidentified nematode, so this agent was not released in Canada.

H. transversovittatus adults are mainly nocturnal, feed on foliage and stem tissue, and can live for several years (Blossey, 1993). Eggs are laid into the lower part of the main shoot or on to the root, with larval development taking 1–2 years. In the field, long wet periods will delay larval development.

G. calmariensis and *G. pusilla* adults emerge from winter diapause in late May to early June and begin feeding on young foliage. Oviposition begins in early June and peaks about mid-June. Larvae feed on shoot tips, foliage and flowers. Peak numbers of larvae occur from late June to early July. Mature larvae pupate in soil around the host plants. First-generation adults occur in August, and in some years well into October. A second generation has been observed in British Columbia, Manitoba and Ontario.

N. marmoratus is univoltine. In Europe, overwintered adults start feeding on young foliage in late May, moving to the upper parts of flower spikes to feed on unopened flowers as flower buds develop (Blossey and Schroeder, 1995). Eggs are laid from June to September, with the female usually depositing one egg into the tip of a young flower bud. Larvae consume the stamens and ovary; attacked buds do not flower and are aborted. New-generation adults appear in August, feeding on foliage prior to overwintering.

Releases and Recoveries

Biological control programmes have been initiated in every province except Newfoundland. A summary of releases is given in Table 74.1.

[1]Starter populations of *H. transversovittatus*, *G. calmariensis* and *G. pusilla* were obtained from Europe via the USA in 1992 and reared at the University of Guelph and the Agriculture and Agri-Food Canada Lethbridge Research Centre for initial Canadian distribution.

Table 74.1. Known liberations of biological control agents against *Lythrum salicaria* in Canada, 1992–1999. Total number of each species released is followed by life stage (A, adult; L, larva; P, pupa; E, eggs) and (number of releases).

Province	Year	*Galerucella calmariensis* L.	*Galerucella pusilla* Duftschmid	*Galerucella* spp.	*Hylobius transversovittatus* Goeze	*Nanophyes marmoratus* Goeze	Total
British Columbia	1993	1308^{A,L} (7)					1308
	1994	1430^{A} (4)	400^{A} (2)		180^{E,L} (1)		2010
	1995	1218^{A} (4)		475^{A} (1)			1693
	1996	453^{A} (2)					456
	1997	3550^{A} (12)	150^{A} (1)				3700
	1998			100^{A} (1)			100
	1999			133^{A} (2)			133
Alberta	1993	388^{A} (2)					388
	1994	100^{A} (1)					100
	1996			75^{A} (1)			75
	1997			175^{A} (1)			175
	1998			200^{A} (2)			200
Saskatchewan	1999	5150^{A} (4)					5150
Manitoba	1992				40^{L} (1)		40
	1993	1981^{A,L} (6)	366^{A} (2)				2347
	1994	1037^{A} (12)	448^{A} (6)		140^{L} (1)		1625
	1995	5883^{A} (12)			1500^{L} (3)		7383
	1996	7650^{A} (15)			550^{L} (1)		8200
	1997	32,500^{A} (15)			1600^{L} (5)	720^{A} (3)	34,820
	1998	50,750^{A} (15)					50,750
	1999	57,190^{A,L} (28)			110^{A} (1)		57,300
Ontario	1992			2800^{L} (6)			2800
	1993			15,700^{A} (50)	300^{L} (2)		16,000
	1994			22,100^{A} (38)	553^{L} (1)		22,653
	1995			30,600^{A} (45)			30,600
	1996			27,950^{A,L} (27)			27,950
	1997			218,965^{A,L,P} (55)			218,965
	1998			80,000^{L} (16)			80,000
	1999			90,000^{L} (12)			90,000
Quebec	1996	1200^{A} (2)	1200^{A} (2)				2400
	1997			8000^{A,L} (8)			8000
	1998			2000^{L} (3)			2000
Nova Scotia	1994			100^{A} (1)	189^{L} (2)		289
	1995			300^{A} (1)			300
	1996			975^{A} (1)			975
	1997			4600^{A} (4)			4600
	1998			31,000^{A,L} (4)			31,000
	1999			100,000^{L} (3)			100,000
New Brunswick	1993		148^{A} (1)				148
	1994	990^{A} (2)	250^{A} (2)				1240
	1995	1000^{A} (2)	800^{A} (2)				1800
	1996			500^{A} (2)			500
	1997			3600^{A} (2)			3600
	1998			20,000^{A} (5)			20,000
	1999			77,000^{L} (5)			77,000
Prince Edward Island	1993	390^{A} (4)	950^{A} (5)				1340
	1994	150^{A}					150
	1996			1400^{A} (4)			1400
	1997			2300^{A} (2)			2300
	1998			20,000^{L,P} (9)			20,000
	1999			50,000^{A} (6)			50,000
Grand total 1992–1999							995,963

H. transversovittatus has been released in British Columbia, Alberta, Manitoba, Ontario and Nova Scotia. At Iona, British Columbia, it is believed that the weevil did not establish due to high tides. In Alberta, larvae were released (within roots of transplanted plants) in 1994 in an open garden plot at Lethbridge, and adults were recovered in 1998 and 1999. In Manitoba, *H. transversovittatus* was released in October, 1992, in the Spruce Woods/Cypress area. Larvae overwintered but no adult weevils have been found to date. In 1996, eggs implanted into cut stems developed and adults were found in 1999. Adults obtained from Cornell University also were released in Manitoba in 1999, near the Libau Marsh. In Ontario, *H. transversovittatus* was released in 1993 and 1994. Releases were discontinued after 1994 because the species was difficult and expensive to rear. It did not establish at any of the Ontario release sites. In Nova Scotia, the status of *H. transversovittatus*, released as larvae in 1994, is uncertain.

N. marmoratus adults were released[2] in 1997 in the Libau Marsh, Manitoba. The population successfully overwintered and reproduced in 1998.

Portions of the initial European importations of *G. calmariensis* and *G. pusilla* were distributed to programmes in Alberta, Manitoba and Ontario in 1992 (Hight *et al.*, 1995). All subsequent Canadian releases of these two species are descended from these populations.

In British Columbia, releases were done annually from 1993 to 1999, with both *Galerucella* spp. being released at 37 sites. It is estimated that 50 to 83% of these have established (R. Cranston, Abbotsford, 1999, personal communication). In Alberta, at one of the three original (1993–1994) release sites near Lethbridge, the beetles established along one side of Gaeol Lake. Releases of *Galerucella* spp. were made at Fort Macleod from 1996 to 1998. Establishment has been confirmed there but beetle numbers are low. The Saskatchewan Purple Loosestrife Eradication Project obtained *G. calmariensis* brood stock (from Manitoba) in 1999 and began mass rearing and releases near Saskatoon and Moose Jaw.

In Manitoba, initial releases of *Galerucella* occurred in 1993. The Manitoba Purple Loosestrife Program has mass-reared *G. calmariensis* from 1994 to 1999, and released this species at over 100 sites from 1993 to 1999. *G. pusilla* was released at eight Manitoba sites in 1993–1994. In an effort to increase agent production, a satellite mass-rearing project was initiated in 1999, involving local stakeholder groups, e.g. the Manitoba Weed Supervisors Association, to rear and release *G. calmariensis* in their local areas.

In Ontario, initial releases of *Galerucella* adults were made at the Speed River, Guelph, in 1992. From 1993 to mid-1996, laboratory-reared *Galerucella* spp. were released at 151 sites into the following general areas: the Grand River watershed around Kitchener–Waterloo and Cambridge, several wetlands in the Mississauga–Burlington area, the Lake St Clair–Detroit River area, the Niagara region, around the lower Bruce Peninsula, the lower Trent watershed, and the Rideau valley watershed. After mid-1996, all Ontario releases were done by redistributing adults and larvae collected from well-established field populations containing both species. In 1996–1997, releases were concentrated in the Grand River watershed as part of a watershed-wide management plan. After termination of the Ontario Program in 1997 (due to lack of funding), a private company continued to make releases with field-collected larvae of both species in 1998 and 1999.

In Quebec, initial releases of adult *Galerucella* spp. in 1996 were along the St Lawrence River and rivers in the Outaouais region, but no establishment occurred (Templeton and Stewart, 1999). In 1997,

[2]The Manitoba Purple Loosestrife Project partnered with Cornell University and the Minnesota Purple Loosestrife Program in autumn, 1996, to collect and import *N. marmoratus* and *N. brevis* from Europe.

adults and larvae, and, in 1998, larvae were released at Lac St François National Wildlife Reserve, near Nicolet, in Hull near the Champlain bridge, and at Cap Tourmente National Wildlife Reserve. In spring, 1998, overwintered adults were found at these release sites (Templeton and Stewart, 1999).

In the Maritimes, *Galerucella* spp. were released from 1993 to 1999 at 23 sites in New Brunswick, by the provincial Department of Agriculture and Rural Development and Ducks Unlimited Canada. The Nova Scotia Agricultural College reared and released beetles from 1994 to 1999. They have established at over 50 sites (G. Sampson, Truro, 1999, personal communication). In Prince Edward Island, beetles have been released at 31 sites since 1993, including Bothwell, Souris, Stratford and Southport (J. Stewart, Charlottetown, 1999, personal communication), and have established at most release sites. From 1997 to 1999, release programmes were intensified in the three Maritime provinces, with over 300,000 *Galerucella* spp. being released at 39 sites.

Evaluation of Biological Control

The biological control programme against *L. salicaria* appears to be developing into a major success. Based upon initial data and observations from across Canada (and the USA), it is apparent that the *Galerucella* spp. alone may be able to effectively control *L. salicaria* in a variety of habitats. In the following discussion, 'control' is considered to mean: (i) over 95% suppression of *L. salicaria* biomass; (ii) over 99% suppression of flowering and seed production; and (iii) substantial replacement of *L. salicaria* with other plant species.

In British Columbia, herbivory damage by *G. calmariensis* released near Chilliwack and at Jericho Park in 1999 was estimated at 90–100% (Myers and Denoth, 1999). In Alberta, populations of *L. salicaria* were suppressed along one side of Gaeol Lake as a result of *G. calmariensis* releases in 1993 and, by 1998, the beetles had dispersed across the lake and established in a new *L. salicaria* stand. In Nova Scotia, *G. calmariensis* had reduced flowering by 80–90% in at least one release site in 1999 (G. Sampson, Truro, 1999, personal communication).

Results from Canada's two largest provincial programmes merit further discussion. In Manitoba, close to 100% control of *L. salicaria* has been achieved at many release sites, including Delta Marsh, areas within the Libau Marsh, Winnipeg River at Great Falls, Red Rock Lake in the Whiteshell, along Highway #317, and sites in the City of Winnipeg. Fixed monitoring stations were established at two release sites in the Libau Marsh and one site in the Delta Marsh, with data collected from 30 randomly tagged stems per site at 10-day intervals from late spring to early autumn. Populations of *G. calmariensis* increased significantly in the third (Delta), fourth or fifth years (Libau sites) after release. In the Libau Marsh, herbivory resulted in all stems being destroyed between 5 and 6 years after release of *G. calmariensis*. The Delta Marsh received the fewest beetles (250), with all *L. salicaria* stems being destroyed by mid-July of each year since 3 years after release. Within a year of explosion of beetle populations, high levels of herbivory resulted in death of all stems at these sites by July to early August. To obtain significant control of *L. salicaria* in Manitoba, *Galerucella* egg densities approaching 600 eggs m^{-2} need to be attained (Diehl, 1999). At the Delta Marsh site, Diehl (1999) reported a 2537% increase in the number of eggs m^{-2} between the second and third years after release. This resulted in a reduction in numbers of stems from 32 to 0 m^{-2}. Diehl (1999) also reported that there was no difference in overwintering survival between the two *Galerucella* spp., that both can tolerate prolonged periods of spring flooding, and that initial dispersal was largely limited to within 5 m of the point of release. An integrated vegetation management strategy is being developed in Manitoba, integrating *G. calmariensis* with herbicide applications (Lindgren *et al.*, 1998, 1999).

Integration of herbicide use with beetles resulted in the most effective suppression of *L. salicaria* stem densities. In herbicide-alone trials, stem densities at the end of the study were greater than before treatment (Henne, 2000).

In Ontario, large populations of the two *Galerucella* spp. (>50 egg masses m^{-2}) were beginning to control *L. salicaria* by 1995 at three of the initial (1992–1993) release sites. By 1999, *L. salicaria* was under control in seven areas of southern Ontario. Densities of 300–600 egg masses m^{-2} have been found in all these areas, and these sites were virtually unrecognizable as *L. salicaria* infestations by 1999 (Bowen, 1998). Effective beetle populations are established in most of the heavily infested areas of southern Ontario, including the Detroit River below Windsor, the western end of Lake Ontario (Bowen, 1998), through much of the Grand River watershed, the Sydenham River in Owen Sound, the Otonabee River in Peterborough, and the Rideau River watershed. Beetles have spread from several release sites (Grand River, Speed River, Etobicoke Creek and Lake Ontario) to occupy at least 100 km of shoreline. The rate of spread is estimated to be 5–10 km $year^{-1}$ from the best release sites. A comprehensive watershed-wide control strategy, initiated in 1996 by the Grand River Watershed Management Plan for Purple Loosestrife, was highly successful. It is anticipated that control of *L. salicaria* will be achieved through most of this watershed in the next 5–10 years. Beetles continue to spread in Ontario, and we believe that they will eventually be found in all of the *L. salicaria* populations in the province.

Of the biological control agents available for *L. salicaria*, *G. calmariensis* has proved highly reproductive, easy to mass-rear, effective and has been the most widely released agent across Canada. Monitoring indicates an *L. salicaria–G. calmariensis* interaction model as follows: significant increases in the *G. calmarienis* population occur as early as the third or fourth year after release, followed by suppression or elimination of *L. salicaria* sexual reproduction, a decline in overall stem height, a reduction in stem number and, finally, a change in the *G. calmariensis* population growth curve from positive to negative as *L. salicaria* is suppressed (Lindgren, 2000). Observations from Ontario further suggest that *G. calmariensis* and *G. pusilla* can coexist and provide effective weed control. At the Ontario sites, the *Galerucella* spp. were released less than 1 km from each other. Populations of the two species subsequently overlapped within 2 years. The coalescence of the two *Galerucella* species at these sites promoted both control and rapid, long-distance dispersal from the original release sites. Finally, in Ontario, effective redistribution of *Galerucella* spp. from successful field sites has been done, with a high rate of establishment and weed control.

Limited feeding by *G. calmariensis* was observed on the native, non-target species *Lythrum alatum* Pursh and *Decodon verticillatus* (L.) Elliott at the Royal Botanical Gardens in Burlington, Ontario (Corrigan *et al.*, 1998). Both of these had been attacked in 'no-choice' host-specificity testing prior to beetle importation into North America (Kok *et al.*, 1992). We believe that the feeding observed at the Botanical Gardens is a short-term, spillover effect, and that these species are not at long-term risk from the biological control agents (Corrigan *et al.*, 1998). The impact of *L. salicaria* on two endangered plant species, *Sidalcea hendersonii* Watson and *Caltha palustris* L., is also under investigation in British Columbia (Myers and Denoth, 1999).

Historically, biological control programmes targeted agricultural weeds. Because *L. salicaria* is a weed of aquatic habitats, it has resulted in new audiences being introduced to biological control of weeds (Blossey *et al.*, 1996). To build support, it is essential that programme objectives and results be communicated to them. The importance of fostering community awareness and involving community partners cannot be overlooked, especially for weeds invading natural areas.

The effort to control *L. salicaria* has been immense, with the involvement of numer-

ous stakeholder groups and contributions from a equally large number of funding agencies across Canada. While *L. salicaria* is an exotic species recognized as a primary invader of natural habitats (White *et al.*, 1993), it is unfortunate that programme funding has restricted and, in some cases, eliminated provincial biological weed control initiatives. Despite the encouraging control results so far, it may be premature to restrict our biological control toolbox to only the *Galerucella* spp. Long-term funding (15–20 years) is needed to further the biological control efforts against *L. salicaria*.

Recommendations

Further work should include:

1. Assessing the establishment and performance of *H. transversovittatus* and *N. marmoratus*;
2. Long-term monitoring of the biological control agents and associated changes in *L. salicaria* populations;
3. Documenting the response of native plant communities;
4. Further developing integrated vegetation management strategies.

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