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Biology and Biological Control of Purple Loosestrife

Second Edition

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Biology and Biological Control of Purple Loosestrife

Second Edition

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New to This Edition

This second edition of the Biology and Biological Control of Purple Loosestrife has been updated to reflect developments in purple loosestrife biological control since 2004, and expanded to include more information on the history, process, safety, and application of classical biological control of weeds as a component of an integrated weed management program. New images have been added to better illustrate identifying characteristics of purple loosestrife, biocontrol agent life stages, and biocontrol agent damage to purple loosestrife plants. Biocontrol agents life stages (eggs, larvae, pupae, adults), life cycle, habitat preference, damage, and current status and availability are described in more detail and in tabular form to facilitateidentification and comparison of biocontrol agents' life cycles and damage. The chapter on biocontrol implementation has been expanded to provide the reader with resources for successfully planning and implementing a purple loosestrife biocontrol program. A new chapter on integrated purple loosestrife management has been added which describes other management tools for purple loosestrife (including physical, cultural, and chemical control) and when and how best to integrate biological control with other management tools as part of a purple loosestrife integrated weed management program.

Contents

Contents (continued)

Contents (continued)

List of Figures

List of Figures
(continued)

List of Figures
(continued)

List of Tables

Chapter 1: Introduction

Overview

Purple loosestrife (*Lythrum salicaria* L., Figure 1) is a large, perennial, wetland plant that can grow up to 9 feet tall (2¾ m). In its native range, purple loosestrife occurs from the United Kingdom east to China and Japan and from Finland south to southern Europe and northern Africa. It was introduced to the northeastern United States and Canada in the 1800s as seed contained in soil used as ship's ballast and in animal wool. It was also intentionally brought to North America for ornamental and medicinal purposes.

Figure 1. Purple loosestrife plant (Jennifer Andreas, Washington State University Extension).

Once established in North America, this invasive weed quickly spread in wetlands and waterways. It is currently reported in all USA states except Florida, Hawaii, and South Carolina and is present in ten Canadian provinces (Figure 2a). Although purple loosestrife is declared noxious in 36 states and five Canadian provinces, it is still sold as an ornamental plant in some places (Figure 2b).

Purple loosestrife invades natural and disturbed wetlands, such as stream banks, lakeshores, marshes, bogs, fens, sedge meadows, canals, drainage ditches, reservoirs, riparian meadows, wet prairies, and sub-irrigated pastures. Established plants can tolerate drier sites, posing a threat to agricultural lands and pastures.

Once established, purple loosestrife quickly crowds out most native vegetation, such as sedges, rushes, cattails, and other wetland plant species. At high densities, purple loosestrife can create near-monocultures. In addition to the loss of native biodiversity, purple loosestrife harms waterfowl nesting habitat, has negative impacts on some amphibians and algal communities, reduces water flow and quality, inhibits transportation, and degrades hunting and fishing areas.

Successful management of purple loosestrife is an intensive process. Pulling small, individual purple loosestrife plants is feasible; pulling large plants is very difficult and often increases the purple loosestrife problem. Mowing and burning are ineffective against purple loosestrife. It is possible that grazing and flooding purple loosestrife can be effective management strategies under the right circumstances, but both can be difficult and/or time-consuming, and may have severe negative, long-term consequences for wetland communities. Herbicides approved for use around water may provide short-term control of very small infestations or isolated plants, but are impractical and uneconomical against large infestations. Similar to grazing and flooding, herbicides may cause severe negative, long-term consequences for wetland

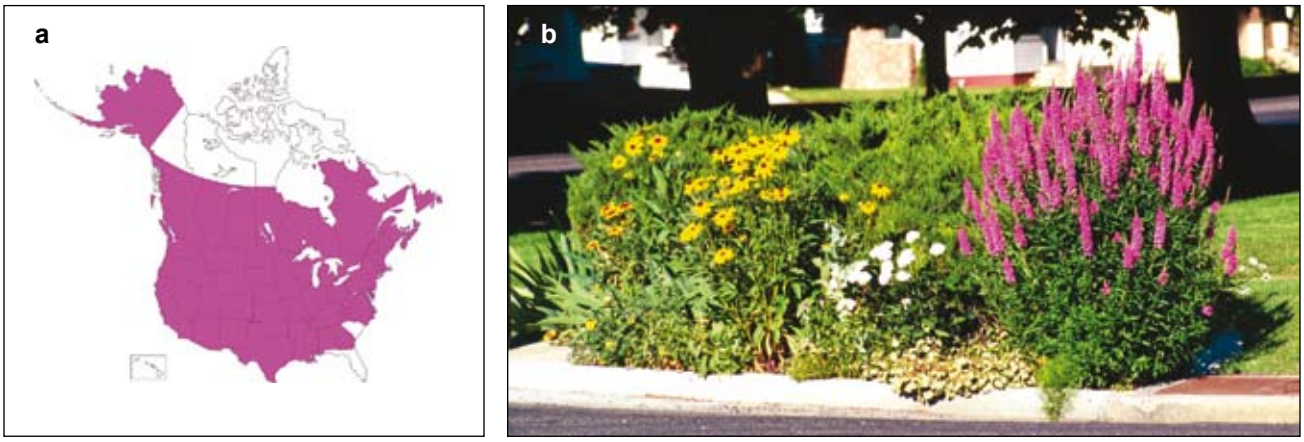


Figure 2. Purple loosestrife a. North American distribution (USDA PLANTS Database, EDDMapS); b. growing as an ornamental (Steve Dewey, Utah State University; bugwood.org).

communities. Due to the difficulties in managing purple loosestrife throughout its invaded range, a biological control program was initiated in 1986. This manual discusses the biological control of purple loosestrife in North America within the larger context of an integrated purple loosestrife management strategy.

Classical Biological Control of Weeds

Most invasive plants, also known as invasive weeds, in the United States are not native to North America; they arrived with immigrants, through commerce, or as hitchhikers from different parts of the world. These non-native plants are generally introduced without their natural enemies, the complex of organisms that feed on the plant in its native range. The lack of natural enemies is one reason plant species become invasive weeds when introduced in areas outside of their native range.

Biological control of weeds (also called "biocontrol") is the deliberate use of living organisms to limit the abundance of a target weed. In this manual, biological control refers to "classical biological control," which reunites host-specific natural enemies from the weed's native range with the target weed in its introduced range. Natural enemies used in classical biological control of weeds include different organisms, such as insects, mites, nematodes, and fungi. In North America, most weed biological control agents are plant-feeding insects, of which beetles, flies, and moths are among the most commonly used.

Biological control agents may attack a weed's flowers, seeds, roots, foliage, and/or stems. Effective biological control agents may kill the weed outright, reduce its vigor and reproductive capability, or facilitate secondary infection from pathogens—all of which reduce the weed's ability to compete with other plants. Root- and crown-feeding biocontrol agents are generally more effective against perennial plants that primarily spread by root buds. Alternatively, flower- and seed-feeding biocontrol agents are typically more useful against annual or biennial plants that only spread by seeds. Regardless of the part of the plant biocontrol agents attack, the aim is to reduce populations of the target weed.

There are advantages and disadvantages to biological control of weeds as a management tool. These are summarized in Table 1.

To be considered for release in North America, it is crucial that weed biocontrol agents are host-specific, meaning they must feed and develop only on the target weed; or in some cases, on a few closely related plant species. Biocontrol agents must never negatively impact any crop or any protected plant species. Tests are necessary in order to ensure that the biocontrol agents are effective and that they will damage only the target weed. Potential biocontrol agents often undergo more than five years of rigorous testing to ensure that host specificity requirements are met.

Table 1. Advantages/disadvantages of classical biological control as a weed management tool

Advantages	Disadvantages
Target specificity	Will not work on every weed in every setting
Continuous action	Irreversible
Long-term cost-effective; can provide sustained control at the landscape scale	Measurable impact may sometimes take several years or even decades. Funding and testing weed biocontrol agents is expensive.
Integrates well with other control methods	Approved biocontrol agents are not available for all exotic weeds.
Generally environmentally benign	Like all weed control methods, “non-target” effects are possible, but pre-release resting reduces the risks.
Self-dispersing, even into difficult terrain	Unpredictable level of control; generally does not eliminate weed

The United States Department of Agriculture’s Animal and Plant Health Inspection Service - Plant Protection and Quarantine (USDA-APHIS-PPQ) is the federal regulatory agency responsible for providing testing guidelines and authorizing the importation of biocontrol agents into the USA. The Canadian Food Inspection Agency (CFIA) serves the same regulatory role in Canada. Federal laws and regulations are in place to identify and avoid potential risks to native and economically valuable plants and animals that could result from exotic organisms introduced to manage weeds. The Technical Advisory Group (TAG) for Biological Control Agents of Weeds is an expert committee with representatives from USA federal regulatory, resource management, and environmental protection agencies, and regulatory counterparts from Canada and Mexico. TAG members review all petitions to import new biocontrol agents into the USA, and make recommendations to USDA-APHIS-PPQ regarding the safety and potential impact of prospective biocontrol agents. Weed biocontrol researchers work closely with USDA-APHIS-PPQ and TAG to accurately assess the environmental safety of potential weed biocontrol agents and programs. In addition, some states in the USA have their own approval process to permit field release of weed biocontrol agents. In Canada, the Biological Control Review Committee (BCRC) draws upon the expertise and perspectives of Canadian-based researchers (e.g. entomologists, botanists, ecologists, weed biological control scientists) from academic, government, and private sectors for scientific review of petitions submitted to the CFIA. The BCRC reviews submissions that are in compliance with the North American Plant Protection Organization’s (NAPPO) Regional Standards for Phytosanitary Measures (RSMP) number 7. The BCRC also reviews submissions to APHIS. The BCRC conclusions factor into the final TAG recommendation to APHIS on whether to allow release of the proposed agent in the USA. When release of an agent is proposed for both the USA and Canada, APHIS and the CFIA attempt to coordinate decisions based on the assessed safety of each country’s plant resources.

Code of Best Practices for Classical Biological Control of Weeds

Biological control practitioners have adopted the International Code of Best Practices for Biological Control of Weeds. The Code was developed in 1999 by delegates and participants of the Tenth International Symposium for Biological Control of Weeds to improve the efficacy of and reduce the potential for negative impacts from biological control. In following the Code, practitioners reduce the potential for causing environmental damage through the use of biological control by voluntarily restricting biocontrol activities to those most likely to result in success.

Although weed biological control is an effective and important weed management tool, it does not work in all cases and should not be expected to completely eradicate the target weed. Even in the most successful cases, biocontrol often requires multiple years before impacts become noticeable. When classical biological control alone does not result in an acceptable level of weed control, other weed control methods (e.g. physical, cultural, or chemical control) may be incorporated to achieve desired results.

International Code of Best Practices for Classical Biological Control of Weeds[1]

1. Ensure that the target weed's potential impact justifies release of non-endemic agents
2. Obtain multi-agency approval for target
3. Select agents with potential to control target
4. Release safe and approved agents
5. Ensure that only the intended agent is released
6. Use appropriate protocols for release and documentation
7. Monitor impact on the target
8. Stop releases of ineffective agents or when control is achieved
9. Monitor impacts on potential non-targets
10. Encourage assessment of changes in plant and animal communities
11. Monitor interaction among agents
12. Communicate results to public

[1] Ratified July 9, 1999, by the delegates to the X International Symposium on Biological Control of Weeds, Bozeman, MT

Biological Control of Purple Loosestrife

One of the key desired characteristics of an introduced weed biological control agent is host specificity. As described above, this is determined by testing to ensure the potential biological control agent feeds only on the target weed and nothing else, or only a few additional species. The testing procedure has become extremely rigorous. The first testing usually involves species closely related to the target weed. For purple loosestrife, the most closely related species are other individuals in the same family (Lythraceae), which includes plants in the same genus (*Lythrum*). There are six native and five exotic species of *Lythrum* growing in continental North America. These are discussed in greater detail in Chapter 2. Some of these species could be affected by purple loosestrife biocontrol agents.

In order for any biological control agent to be approved for release in the United States or Canada, researchers must demonstrate that the agent will not feed and develop on related plants. Following a series of lengthy and involved host specificity tests, in 1991 the loosestrife root weevil, *Hylobius transversovittatus* (Goeze) (Figure 3), and two leaf feeding beetles, *Galerucella calmariensis* (L.) and *Galerucella pusilla* (Duftschmidt) were approved for release. By 1994, one additional species had been approved for release in North America, the flower-feeding weevil *Nanophyes marmoratus* (Goeze). Today, biological control of purple loosestrife is one of the most widely implemented and successful biocontrol of weeds programs in North America.

Figure 3. Adult *Hylobius transversovittatus*, the root-feeding purple loosestrife biocontrol agent (Eric Coombs, Oregon Department of Agriculture).

Integrated Weed Management

The most effective weed management programs vary weed management activities and control methods based on changing weed populations and management objectives over time (termed Integrated Weed Management or IWM). Weed management activities available to managers include education and prevention, physical (hand pulling or mowing), cultural (grazing or fire), chemical (herbicides), and biological control. IWM relies on the development of realistic weed management objectives, accurate weed identification and mapping, appropriate control methods, and post-treatment monitoring to ensure current weed management activities are meeting the weed management goals.

Land managers choose weed control methods that will enable them to achieve their weed management goals or objectives in the most cost-effective manner. No single weed control method will enable managers to meet their purple loosestrife management goals in absolutely all environments or instances. Control method(s) employed in integrated weed management will depend on the size and location of the infested area and specific management goals (e.g., eradication vs. weed density reduction). Very small patches of purple loosestrife may be eliminated with a persistent hand-pulling program, but large infestations will require the use of additional control methods.

Is Biological Control of Purple Loosestrife Right For You?

When biological control is successful, biocontrol agents increase in abundance until they suppress (or contribute to the suppression of) the target weed. As local weed populations are reduced, biocontrol agent populations also decline due to starvation and/or dispersal to other target weed infestations. In many biocontrol systems, there are fluctuations over time with target weeds becoming more abundant, followed by increases in populations of biocontrol agents, until target weed/biocontrol agent populations stabilize at a much lower abundance.

Although biocontrol has provided spectacular suppression of purple loosestrife at many sites in North America, it is not effective at or applicable to every purple loosestrife infestation. We recommend that you develop an integrated weed management program in which biological control is one of several weed management approaches considered. Here are some questions you should ask before you begin a biological control program:

Is my management goal to eradicate the weed or reduce its abundance?
Biological control does not eradicate target weeds, so it is not a good fit with an eradication goal. However, depending on the target weed, biological control agent used, and land use, biological control can be effective at reducing the abundance of a target weed to an acceptable level.

How soon do I need results: this season, one to two seasons, or within five to ten years?
Biological control takes time to work, so another weed management method may be a better choice if you need to show short-term results. Generally, it can take one to three years after release to confirm that biological control agents are established at a site, and even longer for biocontrol agents to cause significant impacts to the target weed. In some weed infestations, 5-30 years may be needed for biological control to reach its full landscape-level weed management potential.

What resources can I devote to my weed problem?
If you have only a small purple loosestrife problem (much less than one acre), weed control methods such as hand pulling and/or the very careful use of herbicides, followed by regular monitoring for re-growth, may be effective. These intensive control methods may allow you to achieve rapid control and prevent the weed from infesting more area, especially when infestations are in high-priority treatment areas such as travel corridors where the weed is more likely to readily disperse. However, if purple loosestrife is well established over a large (> 1 acre) area, and resources are limited, biological control is likely your most effective and economical weed control option.

Is the weed the problem, or a symptom of the problem?
Invasive plant infestations often occur where desirable plant communities have been disturbed. If the disturbance continues without restoration of a desirable, resilient plant community, biological control may not solve your weed problems.

The ideal biological control program:

1. Is based upon an understanding of the target weed, its habitat, land use and condition, and management objectives
2. Is part of a broader integrated weed management program
3. Has considered all weed control methods and determined that biological control is the best option based on available resources and weed management objectives
4. Has realistic weed management goals and timetables
5. Includes resources to ensure adequate monitoring of the target weed, the vegetation community, and populations of biological control agents

About This Manual

This manual provides information on purple loosestrife and each of its biological control agents. It also presents guidelines to establish and manage biological control agents as part of an integrated purple loosestrife management program.

Chapter 1: Introduction provides introductory information on purple loosestrife (including its distribution, habitat, and economic impact) and biological control.

Chapter 2: Getting to Know Purple Loosestrife provides detailed descriptions of the taxonomy, growth characteristics and features, invaded habitats, and occurrence of purple loosestrife in North America. It also describes how to differentiate purple loosestrife from look-alike species.

Chapter 3: Biology of Purple Loosestrife Biological Control Agents describes biological control agents of purple loosestrife, including information on each agent's native range, original source of releases in North America, parts of plants attacked, life cycle, description, host specificity, known non-target effects, habitat preferences, and availability. This chapter is particularly useful for identifying biological control agents in the field.

Chapter 4: Elements of a Purple Loosestrife Biological Control Program includes detailed information and guidelines on how to plan, implement, monitor, and evaluate an effective purple loosestrife biological control program. Included are guidelines and methods for:

- Selecting and preparing biological control agent release sites
- Collecting, handling, transporting, shipping, and releasing biological control agents
- Monitoring biological control agents and vegetation

Chapter 5: An Integrated Purple Loosestrife Management Program discusses the role of biological control in the context of an integrated purple loosestrife management program.

Glossary defines technical terms frequently used by those involved in purple loosestrife biological control.

Selected References lists selected publications utilized to compile this manual.

Appendices:

1. Troubleshooting Guide: When Things Go Wrong
2. Sample Biological Control Agent Release Form
3. Cornell University Purple Loosestrife Monitoring Protocol
4. General Biological Control Agent Monitoring Form
5. Purple Loosestrife Qualitative Monitoring Form
6. Purple Loosestrife Quantitative Monitoring Form

Chapter 2: Getting to Know Purple Loosestrife

Taxonomy and Related Species

Purple loosestrife belongs to the loosestrife family (Lythraceae). In continental North America, this family is represented by ten genera, eight of which are native. The species within the genus *Lythrum* range from annual forbs to perennial subshrubs, and exhibit a wide variety of characteristics. Six species of *Lythrum* are native to North America (Table 2). In addition to purple loosestrife, there are five introduced *Lythrum* species established in continental North America (Table 3), and one additional introduced species in Hawaii (*L. maritimum*).

Table 2. Species of *Lythrum* native to North America

Species	Image	Illustration	Distribution
Lythrum alatum Winged lythrum, wing-angled loosestrife Perennial forb or subshrub			
L. californicum California loosestrife Perennial forb or subshrub			

Table 2 (continued). Species of *Lythrum* native to North America

Species	Image	Illustration	Distribution
L. curtissii Curtiss' loosestrife Perennial forb or subshrub			
L. flagellare Florida loosestrife Perennial forb			
L. lineare Wand lythrum, saltmarsh loosestrife Perennial forb			
L. ovalifolium Low loosestrife Perennial forb			

All distribution data from USDA PLANTS Database; *L. alatum* image: GMayfield10, James Woodworth Prairie Preserve, *L. alatum* illustration: adapted from *Illustrated Companion* to Gleason and Crongquist's manual: *Illustrations of the Vascular Plants of Northeastern United States and Adjacent Canada*, Holmgren 1998; *L. californicum* image: Stan Shebs, *L. californicum* illustration: adapted from *Intermountain Flora*, Cronquist et al. 1997; *L. curtissii* image: Ohio State University Herbarium, *L. curtissii* illustration: Georgia Department of Natural Resources; *L. flagellare* image: John Kunzer, *Atlas of Florida Vascular Plants*, *L. flagellare* illustration: Rachel Winston, MIA Consulting; *L. lineare* image: Larry Allain, hosted by the USDA-NRCS PLANTS Database, *L. lineare* illustration: adapted from *Illustrated Companion* to Gleason and Crongquist's manual: *Illustrations of the Vascular Plants of Northeastern United States and Adjacent Canada*, Holmgren 1998; *L. ovalifolium* image: Bob Harms, Flora of Purola Preserve, N. Hays County, Texas, *L. ovalifolium* illustration: adapted from *Aquatic and Wetland Plants of the Southwestern United States*, Correll and Correll 1995.

Table 3. Species of *Lythrum* introduced to North America

Species	Image	Illustration	Distribution
Lythrum hyssopifolia Hyssop loosestrife Annual or biennial forb Weed			
L. maritimum Pukamole Perennial subshrub Weed			
L. portula Spatula-leaf loosestrife Annual forb Weed			
L. thymifolia Thymeleaf loosestrife Annual forb Weed			

Table 3 (continued). Species of *Lythrum* introduced to North America

Species	Image	Illustration	Distribution
L. tribracteatum Threebract loosestrife Perennial forb Weed			
L. virgatum European wand loosestrife Perennial forb or subshrub Weed; sold as an ornamental (often illegally)			

All distribution data from USDA PLANTS Database; *L. hyssopifolium* image: Javier Martin, *L. hyssopifolium* illustration: adapted from *Illustrated Companion* to Gleason and Crongquist's manual: *Illustrations of the Vascular Plants of Northeastern United States and Adjacent Canada*, Holmgren 1998; *L. maritimum* image: Forest and Kim Starr, *L. maritimum* illustration: adapted from *Manual of the Flowering Plants of Hawai'i*, Wagner et al. 1999; *L. portula* image: Christian Fischer, *L. portula* illustration: Martin Cilenšek 1892, copyright expired; *L. thymifolia* image: José Quiles fotos@florasilvestre.es, *L thymifolia* illustration: Hippolyte Coste - Flore descriptive et illustrée de la France, de la Corse et des contrées limitrophes, 1901-1906, copyright expired; *L. tribracteatum* image: © 2009 Vernon Smith, *L. tribracteatum* illustration: adapted from *Intermountain Flora*, Cronquist et al. 1997; *L. virgatum* image: Radomił Binek, *L. virgatum* illustration: adapted from *Illustrated Companion* to Gleason and Crongquist's manual: *Illustrations of the Vascular Plants of Northeastern United States and Adjacent Canada*, Holmgren 1998.

Purple Loosestrife

Scientific Name: *Lythrum salicaria* L.
Common Names: Purple loosestrife, purple lythrum, spiked loosestrife

Classification

KINGDOM	Plantae	Plants
SUBKINGDOM	Tracheobionta	Vascular plants
SUPERDIVISION	Spermatophyta	Seed plants
DIVISION	Magnoliophyta	Flowering plants
CLASS	Magnoliopsida	Dicotyledons
SUBCLASS	Rosidae	
ORDER	Myrtales	
FAMILY	Lythraceae	Loosestrife family
GENUS	*Lythrum*	Loosestrife
SPECIES	*Lythrum salicaria* L.	Purple loosestrife

Description

At a Glance

Herbaceous, erect perennial (Figure 4) typically growing numerous stems 2-9 feet tall (½-2¾ m) from a spreading, robust root. Stems are squarish in cross-section with 4-6 sides. Leaves are lance-shaped, smooth-margined, stalk-less, and are 2-5 inches long (5-12 cm). Leaves are opposite up the stem, and whorled closer to the base. Flowers are less than 1 inch across (2½ cm) with 5-7 pink to purple (sometimes crumpled-looking) petals. Flowers occur in spiked clusters from summer to early fall. Each flower can produce well over 100 small, light-colored seeds.

Figure 4. Purple loosestrife plant (Caitlin Stewart, Hamilton County Soil & Water Conservation District, New York).

Roots

Purple loosestrife develops a strong root as a seedling, which branches into secondary and tertiary roots with age. Main root and major root branches are woody (Figure 5a). The root crown is wide-topped, reaching up to 5 feet in diameter (1½ m). Plants re-sprout each year from these large root systems, and root fragments cut from the plant can reportedly produce new plants in some situations.

Stems

Plants typically grow 2-9 feet in height (½-2¾ m) and consist of multiple stems growing in clumps of up to 50 from a single root crown. Stems are squarish in cross section with 4-6 sides (Figure 5b). They can be either smooth or covered with downy hairs and become woody and darker-colored in the fall. Stems have short, slender branches and evenly spaced nodes. Stems die back each year and are replaced by new shoots produced each spring from buds on the persistent root system. Dead stems persist through the winter and often decay slowly, creating a persistent mat for several years in dry environments.

Leaves

Leaves are 2-5 inches long (5-12 cm) and typically ¼-⅔ inches wide (6-15 mm). They do not have petioles (small stalks that attach leaves to

plant stems). Leaves are lance-shaped, smooth-margined, and have heart-shaped or rounded bases (Figure 5c). Leaves are arranged in whorls of three closer to the plant base, but grow opposite and smaller further up the stem. The uppermost leaves may sometimes appear alternate.

Flowers

The inflorescence of purple loosestrife is a spike of numerous, showy, reddish-purple or magenta flowers set in clusters (Figure 6a). Each flower is ⅓-¾ inches (8-20 mm) in diameter, has 5-7 petals (often appearing crumpled), and has a small, yellow center (Figure 6b). Flowering occurs from mid-June to late September, depending on location.

Seeds

Seeds are contained in narrow, cylindrical capsules ¼ inch (6 mm) in length (Figure 6c). Each capsule opens upon maturity to release more than 100 tiny, light-colored seeds (Figure 6d). A single plant may produce more than 100,000 seeds annually, sometimes up to a few million.

Figure 7 illustrates various characteristics of the purple loosestrife plant.

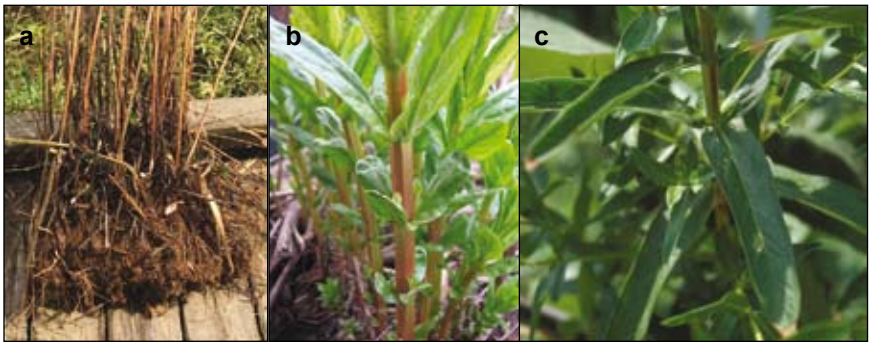


Figure 5. Purple loosestrife a. root crown; b. stem and opposite leaves (a,b Jennifer Andreas, Washington State University Extension); c. whorled leaves (Theodore Webster, USDA Agricultural Research Service; bugwood.org)

Figure 6. Purple loosestrife a. inflorescence (Jennifer Andreas, Washington State University Extension); b. flower (Linda Wilson, University of Idaho); c. fruits (Leslie J. Mehrhoff, University of Connecticut); d. fruit and seeds (Gary L. Piper, Washington State University) (b-d bugwood.org)

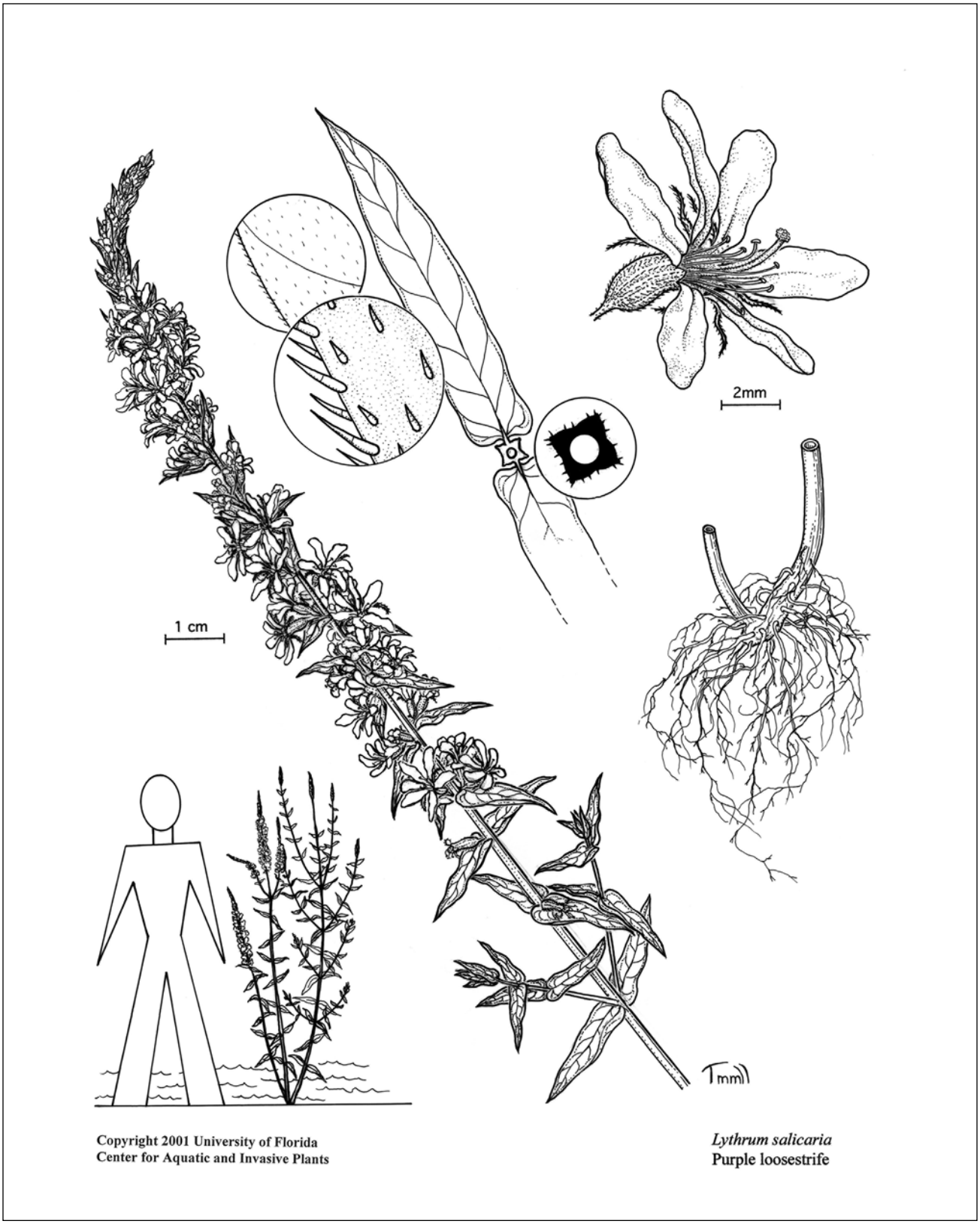


Figure 7. Line drawing of purple loosestrife key traits (University of Florida/IFAS Center for Aquatic and Invasive Plants).

Biology and Ecology

Purple loosestrife seed can be dispersed short distances by wind (typically <33 feet or 10 m), and longer distances by humans, other animals, and water. Seeds are released fall through winter and may remain viable for more than three years, potentially much longer. As is typical for many wetland plant species, germination is restricted to seeds exposed at the soil surface at high temperatures (68 °F or 20 °C and above) or in shallow water.

Seedlings germinate in late spring or early summer when soil temperatures reach 68 °F (20 °C). Many first-year plants are over 3 feet tall (0.9 m), and many even flower. The mature size of the plant will depend on soil type and fertility, water level, and plant density. Flowering occurs from summer to fall. After the first extreme frosts in fall, all above-ground plant parts die back. Plants re-sprout each spring from their large root systems (Figure 8a).

Purple loosestrife spreads primarily by seeds. Stems harbor adventitious buds that, if buried, have the ability to produce new shoots or roots. Breaking off buried stems or roots during incomplete plant removal initiates shoot growth. These sprouting pieces may generate new infestations when they float downstream and lodge against a stream bank, though this type of spread is not reportedly common.

Habitat

Any sunny or partially shaded wetland is susceptible to purple loosestrife invasion. Infestations are frequently found along streams, rivers, irrigation canals, lakes and ponds, and in swamps and freshwater tidal flats. Although purple loosestrife generally prefers moist soils, mature purple loosestrife plants can tolerate a wide range of water levels, pH and climatic conditions, soil, and vegetation types. Consequently, purple loosestrife can be problematic in seasonally wet meadows and wet prairies, and infestations can expand from moist locations into neighboring areas with drier conditions. In flooded areas, the plant forms monocultures with dense, fibrous mats (Figure 8b).

Distribution

As of 2015, purple loosestrife is considered established in all USA states except Florida, Hawaii, and South Carolina and is present in ten Canadian provinces (Figure 2a, repeated here in Figure 9a). It has been declared noxious in 36 states and five Canadian provinces (Figure 9b).

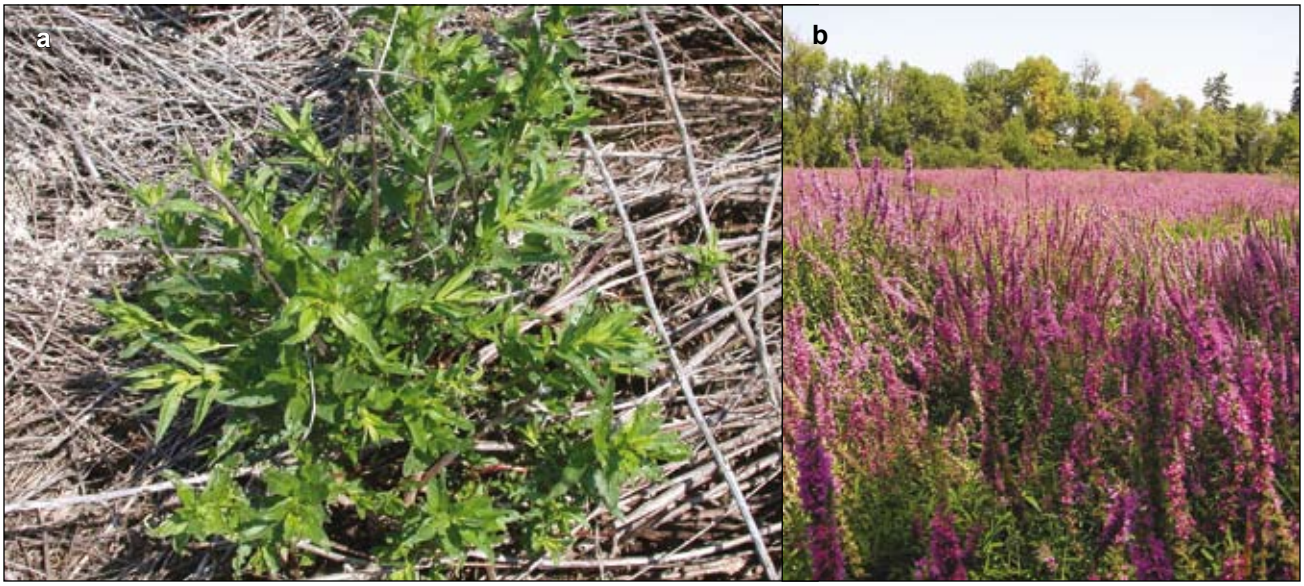


Figure 8. Purple loosestrife a. sprouting from root system amid previous year's dead stems (Carol Bell Randall, USDA Forest Service; bugwood.org); b. monoculture (Eric Coombs, Oregon Department of Agriculture; bugwood.org).

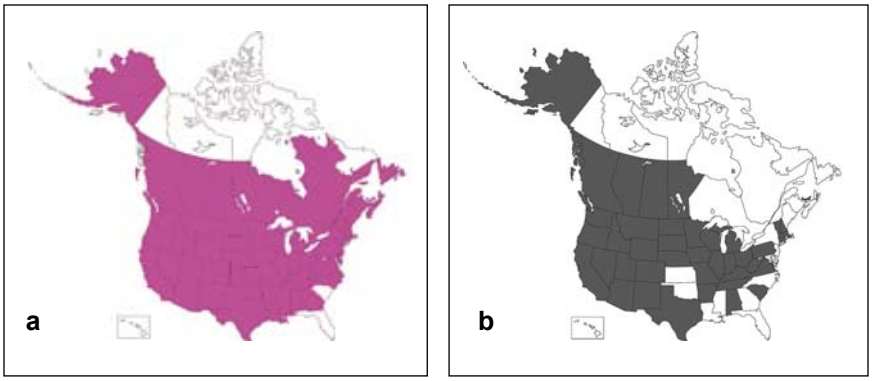


Figure 9. States and provinces where purple loosestrife is a. established (USDA PLANTS Database, EDDMapS); b. listed as noxious.

Comments

Although still sold and planted for its beauty as an ornamental, purple loosestrife's habit of devastating waterways and wetlands has caused its sale to become restricted or, in many states, illegal. Where distribution of the species is restricted, many sterile 'varieties' sold are generally not sterile as advertised. The closely related European wand loosestrife, *Lythrum virgatum*, is also widely sold as an ornamental, despite being listed as noxious in some parts of the USA. Some botanists consider this to be the same species as purple loosestrife (*L. salicaria*). Even when the species are believed to be separate, gardeners and wholesalers frequently confuse their identities, and it is often the more highly prohibited purple loosestrife (or their hybrid) that is for sale. Extreme caution should be applied when considering or encountering either species in an ornamental setting.

Commonly Confused Species

In addition to the related *Lythrum* species described in Tables 2 and 3, there are unrelated species present in North America that have an appearance similar to purple loosestrife. The species most closely resembling purple loosestrife are listed in Table 4, along with key characteristics that can be used to differentiate the look-alikes.

Table 4. North American species similar in appearance to purple loosestrife, and key traits for differentiation

Species	Image	Differentiating Features
Blue vervain, swamp verbena *Verbena hastate* Verbena Family Native biennial or perennial forb		Blue vervain grows in habitats similar to purple loosestrife, but does so from rhizomatous roots. Blue vervain stems are square, always with 4 sides. Blue vervain leaves are opposite, rough, and coarsely toothed along their margins. Flowers of blue vervain are tubular at their bases, have 5 bluish-purple petals, and occur in clusters much more narrow than purple loosestrife inflorescences.
Fireweed, great willow-herb *Chamaenerion angustifolium* subsp. *angustifolium* (previously *Epilobium angustifolium*) Willowherb Family Native perennial forb		While fireweed can tolerate moist conditions, it is frequently found on hillsides and slopes, especially following disturbance events such as forest fires. Such conditions are typically unsuitable for purple loosestrife. Fireweed has a fibrous and rhizomatous root system and round stems. Fireweed leaves are alternate, have very short petioles, and are narrower than purple loosestrife leaves. Fireweed flowers have 4 petals, white or pink centers, and occur in looser clusters than purple loosestrife.
Hardhack, rose spirea *Spiarea douglasii* Rose Family Native shrub		Though it grows in a similar habitat to purple loosestrife, hardhack is a woolly shrub growing from rhizomatous roots. Hardhack stems are round, and its oval leaves are alternate, whitish on their undersides, and have margins that are toothed from their midpoints to their tips. Hardhack flowers have pink centers, 5 petals, and occur in more dense clusters than purple loosestrife.

Blue vervain (R.A. Nonenmacher); Fireweed (Kallerna); Hardhack (Meggar)

Chapter 3: Biology of Purple Loosestrife Biocontrol Agents

Basic Insect Biology

Insects are a very large, diverse class of animals. Basic knowledge of insect anatomy and lifecycle will help in understanding insects, and recognizing them in the field.

Most insects used in weed biocontrol have complete metamorphosis, which means they exhibit a life cycle with four distinct stages: egg, larva, pupa, and adult (Figure 10a). Adult insects have an exoskeleton (a hard external skeleton), a segmented body divided into three regions (head, thorax, and abdomen, Figure 10b), and three pairs of segmented legs attached to the thorax. The head of an adult insect has one pair each of compound eyes and antennae.

Because insects have an external skeleton, they must shed their skeleton in order to grow. This process of shedding the exoskeleton is called molting. Larval stages between molts are called "instars." Larvae generally complete three to five instars before they molt into pupae. During the pupal stage, insects change from larvae to adults. Insects do not feed during the pupal stage.

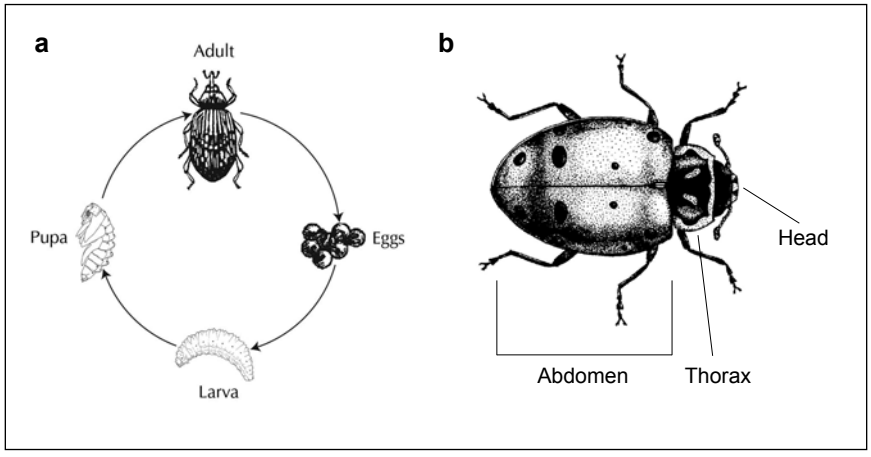


Figure 10. Line drawings of beetle a. lifecycle showing complete metamorphosis (University of Idaho); b. anatomy (adapted from Biological Control of Weeds in the West, Rees et al. 1996).

Purple Loosestrife Biological Control Insects

All four of the insect species permitted for purple loosestrife biocontrol in the United States and Canada are beetles. Beetles are hard-bodied insects with tough exoskeletons. Adult beetles possess two pairs of wings. The two front wings, called elytra, are thickened and meet in a straight line down the abdomen when at rest, forming a hard, shell-like, protective covering. The two hind wings are membranous and used for flight. These are larger and are folded under the elytra when not in use. Beetle larvae are grub- or worm-like with three small pairs of legs, and some are quite mobile. Many are pale white with a brown or black head capsule, though some may be quite colorful and change markedly in appearance as they grow. Beetles, like those used for purple loosestrife biocontrol, have chewing mouthparts.

Two of the purple loosestrife biocontrol agents are leaf beetles (family Chrysomelidae), and the other two are weevils (superfamily Curculionoidea). Leaf beetles are small, foliage-feeding beetles; both adult leaf beetles and their larvae feed externally on plant foliage. Larval feeding often is more damaging, though both can result in complete defoliation of plants. Weevils are plant-feeding beetles with long snouts bearing chewing mouthparts at the tip. They use the snout to chew and feed on plant tissues, or to notch out holes in which to lay their eggs. Weevil larvae feed internally in the stems, roots or flowers of their target plants.

The four species used for purple loosestrife biocontrol attack three distinct parts of the plant (Figure 11). The two leaf beetles attack the foliage, one weevil attacks the plant's roots, and the remaining weevil feeds on purple loosestrife flowers. Each species is described in the following sections.

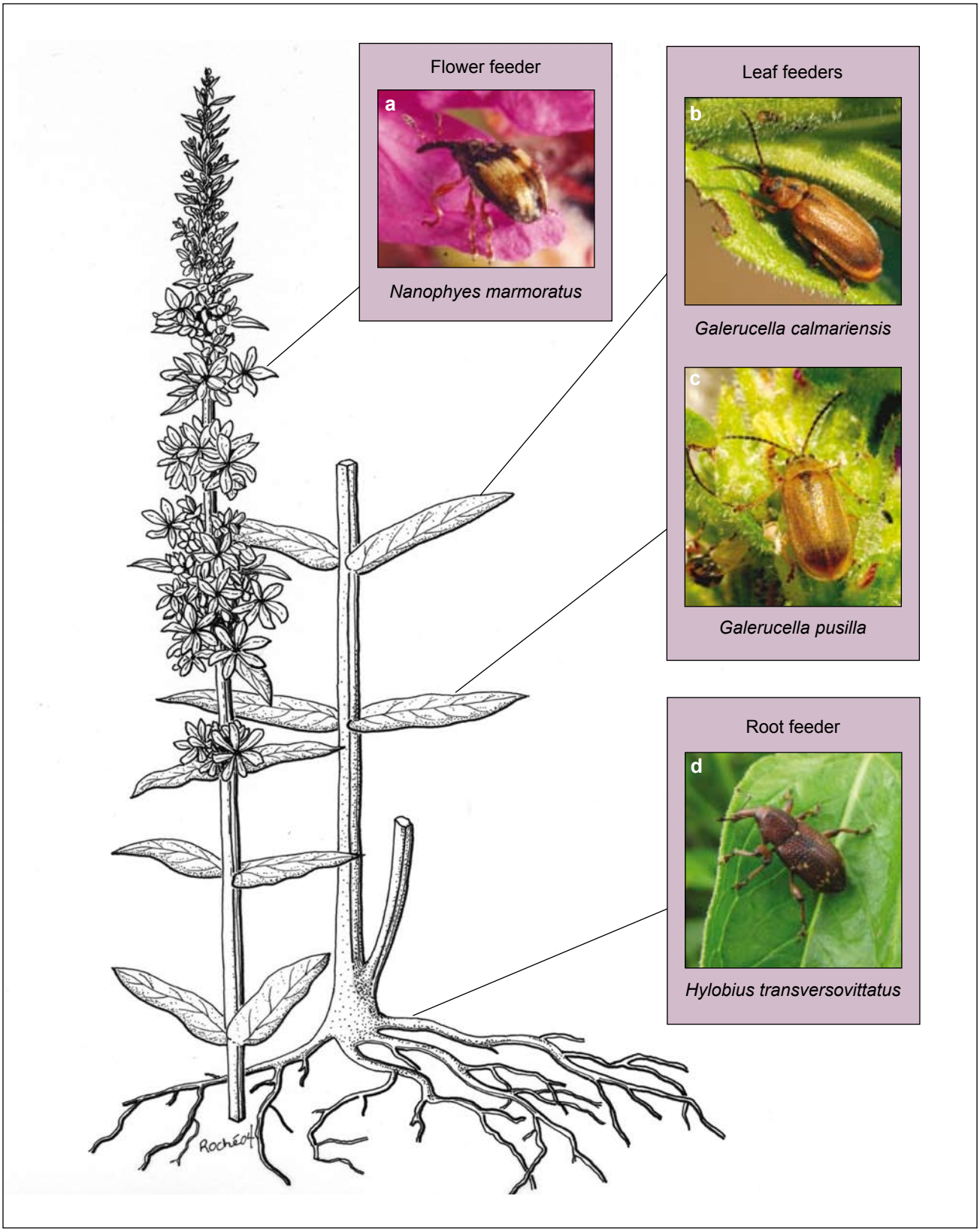


Figure 11. General location of greatest attack by purple loosestrife biological control agents. (Plant: Cindy Roche, adapted from Thompson et al. 1987); a. *Nanophyes marmoratus* (Mark Schwarzländer, University of Idaho; bugwood.org); b. *Galerucella calmariensis* (David Cappaert, Michigan State University; bugwood.org); c. *G. pusilla* (Eric Coombs, Oregon Department of Agriculture); d. *Hylobius transversovittatus* (Jennifer Andreas, Washington State University Extension).

Galerucella calmariensis (L.) and *G. pusilla* (Duftschmidt)

Black-margined loosestrife beetle and **Golden loosestrife beetle**

ORDER	Coleoptera
FAMILY	Chrysomelidae
NATIVE DISTRIBUTION	Eurasia
ORIGINAL SOURCE	Germany
FIRST RELEASE	USA & CAN: 1992
NONTARGET EFFECTS	Multiple species

Description

Galerucella calmariensis and *G. pusilla* are two nearly identical species of leaf-feeding beetles that cannot be distinguished in the egg or larval stage. Eggs are small (½ mm wide), spherical, and white, often with a black line of frass (Figure 12a,b). Larvae are up to 5 mm long. They are greenish-yellow with darkened head capsules and black spots down their backs (Figure 12c). Adults of both species are typically 5 mm long. Adult *G. calmariensis* are orange-brown and typically have darkened edges to their hard, outer wings and a dark triangle behind their head (Figure 13a). Adult *G. pusilla* are light gold to orange-brown with dark antenna from the middle to the tips (Figure 13b). Their differences in coloration develop fully only in overwintered beetles. Females of both species are slightly larger than males.

Figure 12. *Galerucella* spp. on purple loosestrife a. egg clusters (Doug Landis, Michigan State University; bugwood.org); b. eggs and larva (Bernd Blossey, Cornell University; bugwood.org); c. larva (Agriculture and Agri-Food Canada Archive; bugwood.org).

Figure 13. Adult a. *Galerucella calmariensis* (David Cappaert, Michigan State University; bugwood.org); b. *G. pusilla* (Eric Coombs, Oregon Department of Agriculture).

Life Cycle

Overwintering adults emerge and feed on leaves and young shoot buds in early spring as soon as purple loosestrife shoots emerge. After mating, females lay up to 400 eggs in groups of 2-10 on stems and leaves from late spring through summer. Larvae hatch after about one week and move to leaf buds where they remain well concealed as they feed. Older larvae openly feed on leaves and developing inflorescences. There are three larval instars. Mature larvae move into the litter beneath purple loosestrife plants to pupate. On flooded purple loosestrife, pupation occurs in the spongy tissue (called aerenchyma) that develops on the flooded portion of the stem (Figure 14). Development time from egg to adult is 30-40 days (Figure 15). New adults emerge in late summer, resume feeding, and then overwinter in plant litter. Both species usually have only one generation each year, but a partial second generation may occur. If a second generation develops, new adults may emerge as late as the end of August. Adult loosestrife beetles are very good fliers, and they can easily find new patches of purple loosestrife on which to feed and reproduce. Loosestrife beetle adults are known to disperse 2-4 miles (3.2-6.4 km) a year on average.

Figure 14. *Galerucella* spp. larvae and pupae in purple loosestrife aerenchyma (Eric Coombs, Oregon Department of Agriculture).

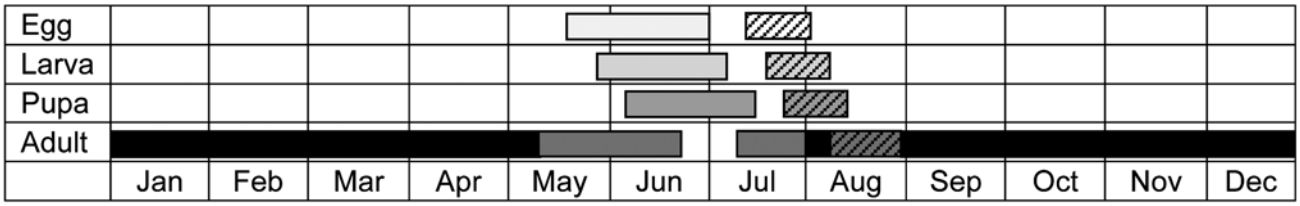


Figure 15. Schematic life cycle of *Galerucella calmariensis* and *G. pusilla*. Bars indicate the approximate length of activity for each life stage. Black bars represent the inactive overwintering period. Short patterned bars represent the activity of a potential second generation. Biocontrol agent stages may vary according to local climate and habitat conditions.

Habitat Preference

Both species are established in numerous states and provinces, spanning a wide variety of climatic conditions. Although they can survive under a range of conditions, they do not thrive in shade or in areas with long winter flooding or where water levels fluctuate dramatically (e.g., dam reservoirs or tidal flats). Adults require a dry area in order to overwinter successfully. Where purple loosestrife is growing in standing water, adults frequently move to higher sites or taller neighboring vegetation to overwinter, before re-colonizing flooded plants in spring.

Damage

Larval feeding strips the photosynthetic tissue off leaves while leaving the upper leaf cuticle and epidermis intact, creating a "window-pane" effect (Figure 16a,b). Adult feeding causes a characteristic "shot hole" defoliation pattern (Figure 16c). Larval and adult feeding stunt plant growth and reduce seed production. While plants may recover after defoliation and flower late in the year, in some areas loosestrife beetle feeding has completely suppressed summer flowering (plants may produce flowers in mid to late summer, but have difficulties attracting pollinators and setting seed). Heavy defoliation may kill plants outright over several years and at high beetle densities. This has dramatically reduced purple loosestrife populations at many sites.

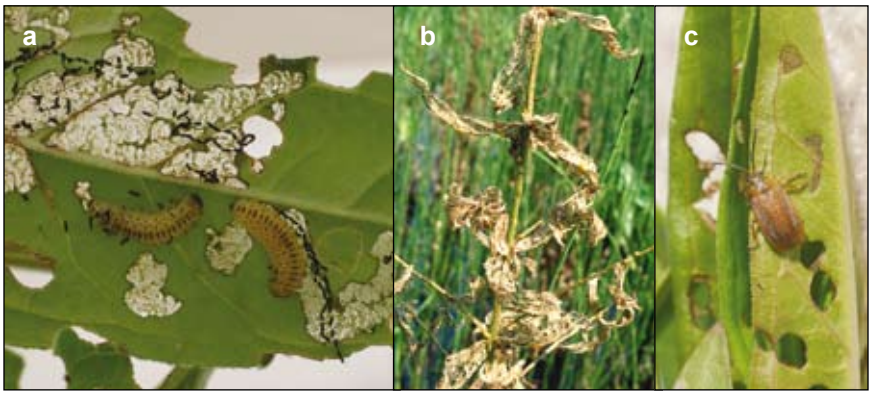


Figure 16. *Galerucella* spp. damage: a. larval window-pane feeding on a leaf (Bernd Blossey, Cornell University; bugwood.org); b. larval window-pane feeding on entire plant (Linda Wilson, University of Idaho; bugwood.org); adult shot-hole feeding on a leaf (Eric Coombs, Oregon Department of Agriculture; bugwood.org).

Current Status and Availability

Both species are established throughout much of North America (Figure 17). In the United States, they are well established in some states but infrequent in others. *Galerucella calmariensis* is generally thought to be more abundant than *G. pusilla*, but the reverse is true at some sites for unknown reasons. There are no comprehensive surveys so the status of the two species needs confirmation. High densities have heavy impact on purple loosestrife plants by reducing seed production and stunting growth. At some sites where one or both biocontrol agents established, purple loosestrife density has decreased up to 90 percent; at others, purple loosestrife density remains unchanged. Fluctuations in purple loosestrife abundance are common for this system: as *Galerucella* populations build, greater dispersal results in increases in the weed population, followed by increases in agent populations. Impact is greatest in mixed plant communities that provide competition to recovering loosestrife. In Canada, both *Galerucella* species again often appear in a mix. According to Canadian sources, together they have provided excellent control throughout the majority of purple loosestrife's range. Both *Galerucella* species were initially widespread, but more recent surveys indicate populations at many sites now consist primarily or wholly of *G. calmariensis*.

Nontarget Effects

Following mass outbreaks of *Galerucella* spp. in the United States, limited spillover feeding was observed on the native *Salix discolor*, *Potentilla anserina*, *Cornus sericea* subsp. *sericea*, and *Decodon verticillatus*, as well as the exotic *Rosa multiflora*. The feeding observed on these nontarget plants was short-lived and did not result in nontarget plant mortality. A recent mass outbreak in Oregon (2015) resulted in adult *Galerucella* spp. feeding for a short period of time on crepe myrtle (*Lagerstroemia indica*), roses (*Rosa* spp.), sunflowers (*Helianthus* spp.),

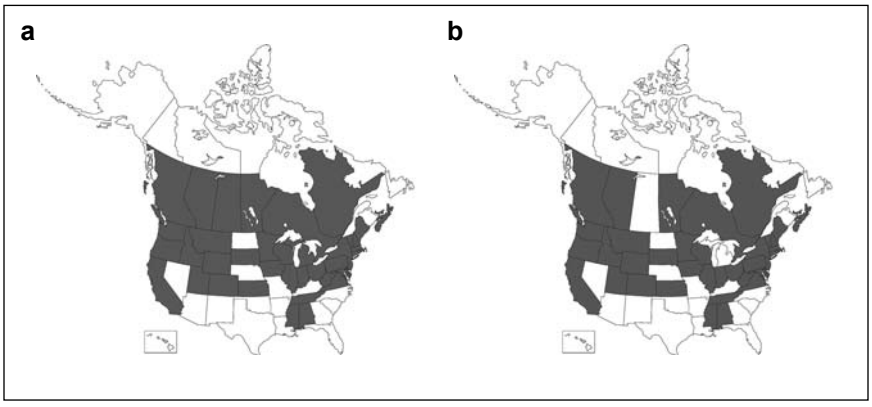


Figure 17. North American establishment of a. *Galerucella calmariensis*; b. *G. pusilla*.

nightshade (*Solanum* sp.), pomegranate (*Punica granatum*) and oak trees (*Quercus* spp.), and other species immediately adjacent to a purple loosestrife infestation that had been completely defoliated. In Canada, temporary adult feeding by *G. calmariensis* has been recorded on the native *D. verticillatus* and *Lythrum alatum*.

Comments

Predators and parasites of *Galerucella* spp. have been reported in North America, although the specialist wasps that attack these species in Europe were carefully excluded when beetles were imported. Adult loosestrife beetles can be parasitized by a nematode that feeds and develops inside the beetle, eventually killing it. Other native predators of loosestrife beetles are ladybeetles, true bugs, predaceous beetles, spiders, and possibly birds, frogs, and lizards.

Hylobius transversovittatus (Goeze)

Loosestrife root weevil

ORDER	Coleoptera
SUPERFAMILY	Curculionoidea
FAMILY	Curculionidae
NATIVE DISTRIBUTION	Eurasia
ORIGINAL SOURCE	USA: Germany, Finland, Austria, France, Sweden, Switzerland CAN: Germany, Finland, Austria, France, Sweden, Switzerland
FIRST RELEASE	USA: 1992 CAN: 1992
NONTARGET EFFECTS	None reported

Description

Eggs are white and oval-shaped (Figure 18a). Larvae are C-shaped, off-white, and have brown head capsules (Figure 18b). They can be up to 10 mm long. Adults are reddish-brown and have two rows of dots on their backs that are comprised of white hairs (Figure 18c). They are thick insects up to 12 mm long.

Life Cycle

This species often requires two years to complete one generation (Figure 19). Overwintering larvae become more active in early spring, feeding on roots and filling feeding tunnels with frass. They develop through three instars. Pupation occurs in the root crown mainly in early summer. Emerging adults feed on purple loosestrife leaves and stems and mate within two weeks. Females lay eggs singly (up to 100 annually) in the soil or in purple loosestrife stems near the soil surface. Larvae hatch

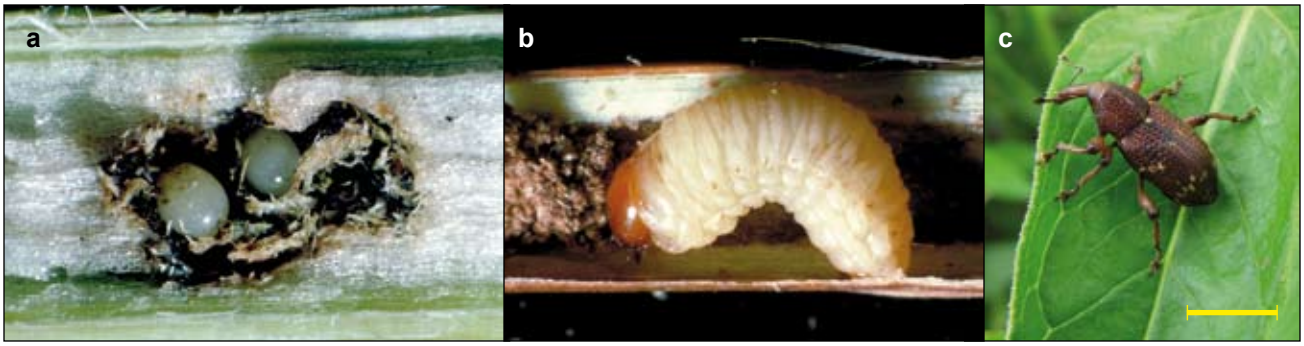


Figure 18. *Hylobius transversovittatus* a. eggs; b. larva and stem damage (a,b Gary Piper, Washington State University; bugwood.org); c. adult (Jennifer Andreas, Washington State University Extension).

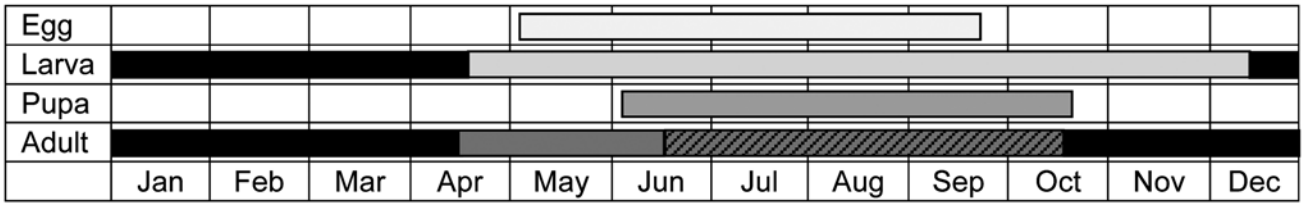


Figure 19. Schematic life cycle and activity periods of *Hylobius transversovittatus*. Bars indicate presence of different life stages in or at the plant. Hatched bars represent emergence of adults. Black bars represent inactive periods during winter. Depending on local climates, flooding events, and time of oviposition, some larvae may need up to two years to complete development. Very occasionally a pupa may overwinter. Adults are long-lived and may live up to three years but can reproduce soon after emergence. Life cycles and longevity may vary according to local habitat conditions and climate.

in about eleven days and start to mine the root hairs (if hatched from eggs laid in the soil) or into the stem. Larvae later feed on the outside of the root, and then mine into the root center where they overwinter and then continue to feed for one to two years. Larvae are active as long as soil temperatures allow. Flooding of roots causes feeding activity to cease, but larvae can tolerate long periods (many weeks) of submergence.

Adults overwinter, and can live up to three years. Overwintering adult weevils appear shortly after purple loosestrife shoots sprout. Adults are most active at night, but can be found on their host plants in the early evening and morning hours or during cool, overcast, or rainy days. During warm, sunny days, they hide in the litter, often at the base of the plants.

Habitat Preference

The loosestrife root weevil tolerates a wide range of environmental conditions. Though adults and larvae can survive extended submersion, permanently flooded sites will prevent adult access to plants and will eventually kill developing larvae.

Damage

Adult feeding is typically not significant (Figure 20a). The impacts of larval feeding vary depending on the size and age of the root system, the density of purple loosestrife plants, and the number of weevils at the site. At high larval densities, small root systems can be severely damaged or killed (Figure 20b). Large roots can withstand substantial feeding pressure, and several larval generations will be necessary before significant impacts are observed. Attacked plants have reduced reserve capacity leading to an overall smaller size, lower seed production, and sometimes even plant death.

Current Status and Availability

In the United States, *Hylobius transversovittatus* is slower to disperse and reproduce than the other established agents. It is believed to have well-established populations in Oregon, New York, Minnesota, and perhaps Washington and Idaho, but our information is largely limited elsewhere (see Figure 21) due to difficulties in confirming this secretive root feeder. It may be well established throughout the range of purple loosestrife in North America. Extensive root feeding by this biocontrol agent can complement defoliation by *Galerucella* spp., often resulting in plant death. However, *Hylobius* establishment and impact are both difficult to fully assess as larvae are hidden feeders, and adults are most active at night.

Comments

Up to 40 larvae have been found per root system.

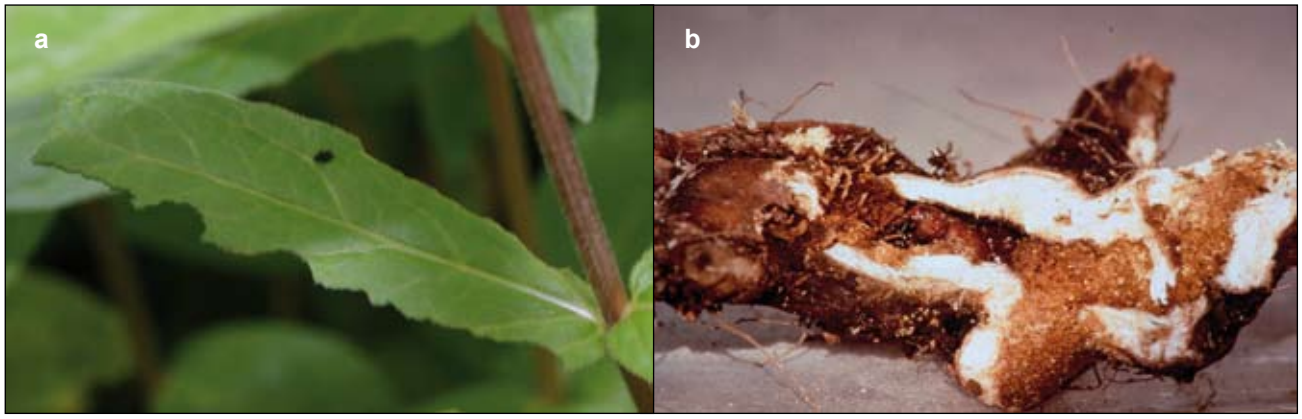


Figure 20. *Hylobius transversovittatus* feeding damage to a purple loosestrife a. leaf (Eric Coombs, Oregon Department of Agriculture); b. root (Bernd Blossey, Cornell University; bugwood.org)

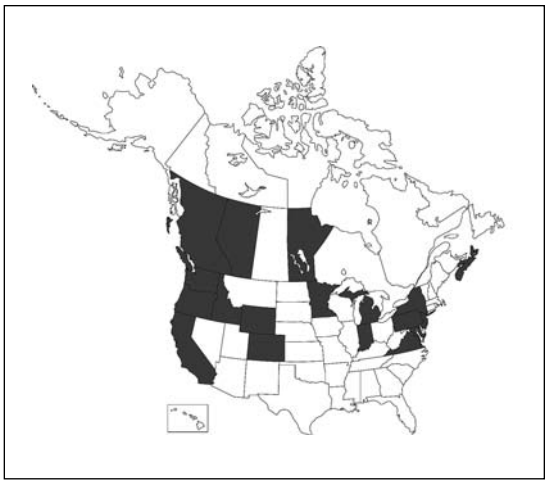


Figure 21. Confirmed North American establishment of *Hylobius transversovittatus*.

Nanophyes marmoratus (Goeze)

Loosestrife flower weevil

Order	Coleoptera
Superfamily	Curculionoidea
Family	Nanophyidae
Native Distribution	Eurasia
Original Source	USA: Germany, France CAN: Germany
First Release	USA: 1994 CAN: 1997
Nontarget Effects	None reported

Description

Eggs are tiny, spherical, and white (Figure 22a). Larvae are C-shaped, creamy white, and have brown head capsules (Figure 22b). They can be up to 2 mm long. Adults are dark brown with orange legs and large, whitish-yellow shoulder patches (Figure 22c). Adults are very small (up to 2½ mm long) and have a long snout and wide body.

Figure 22. *Nanophyes marmoratus* a. egg; b. larva in flower bud (a,b Gary Piper, Washington State University; bugwood.org); c. adult (Mark Schwarzländer, University of Idaho; bugwood.org).

Life Cycle

Overwintering adults emerge in late spring and feed on purple loosestrife shoot tips and young leaves. As soon as flower buds develop, the adults move to the flower spikes, where they feed on the buds, mate, and begin to lay eggs. Females lay 60-100 eggs singly inside immature flower buds throughout summer during the purple loosestrife flowering period. Hatching larvae develop through three instars and feed on floral parts. Pupation occurs in the base of attacked buds. New adults emerge in late summer and feed on the remaining green leaves of purple loosestrife before seeking overwintering sites in plant litter. Holes chewed in the buds when the adult flower weevils emerge from their pupation chambers provide evidence that the weevil is present at the site. There is one generation per year. Complete development from egg to adult takes about one month (Figure 23).

Habitat Preference

The loosestrife flower weevil is well adapted to a variety of environmental conditions throughout the range of the weed in North America. It does not do as well at sites with very high populations of *Galerucella* spp. because heavy defoliation by the leaf-feeders reduces food availability.

Damage

Adult and larval feeding cause flower bud abortion (Figure 24a,b), which reduces the seed output of purple loosestrife. At high loosestrife flower weevil densities, larval feeding can reduce seed output of a purple loosestrife plant by up to 60 percent. This does not kill existing plants, but can help reduce the rate of spread.

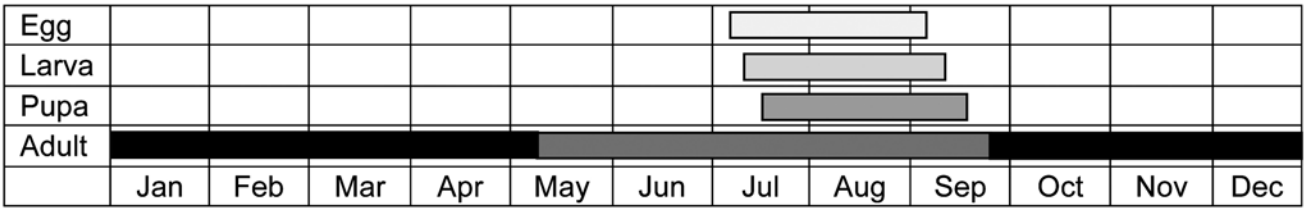


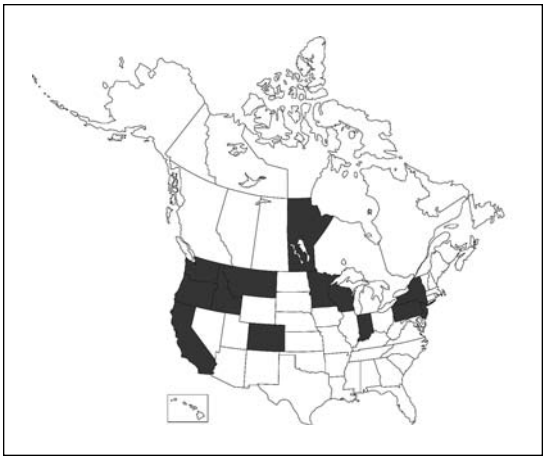
Figure 23. Schematic life cycle of *Nanophyes marmoratus*. Bars indicate the approximate length of activity for each life stage. Black bars represent the inactive overwintering period. Biocontrol agent stages may vary according to local climate and habitat conditions.

Figure 24. *Nanophyes marmoratus* a. adult exit hole in a dead purple loosestrife bud (Gary Piper, Washington State University; bugwood.org); b. damage resulting in 100% abortion of buds on an attacked inflorescence (right) next to inflorescences not attacked (left) (S. Schooler, Oregon State University; bugwood.org).

Current Status and Availability

In the United States, *Nanophyes marmoratus* feeding on floral buds often results in bud abortion, which helps reduce purple loosestrife spread. However, flower weevil populations are sometimes limited due to interspecific competition with *Galerucella* spp. (defoliated purple loosestrife plants often do not flower, removing *N. marmoratus*' food supply). Though the flower weevil should not be released at sites with high populations of *Galerucella* spp., *N. marmoratus* is often complementary to the leaf beetles by attacking flowers on purple loosestrife plants that escape defoliation. The flower weevil is an important biocontrol agent at sites with decreasing loosestrife and smaller populations of the other biocontrol species. In Canada, though the flower weevil is established, it only occurs in Manitoba, and its abundance and impact are not known (Figure 25).

Figure 25. North American establishment of *Nanophyes marmoratus*.



Comments

Nanophyes marmoratus has successfully overwintered on exposed islands in an estuary with high tidal exchange where multiple releases of *Galerucella* spp. have failed. The loosestrife flower weevils can also persist where plants are scattered at low densities.

The taxonomic placement of the genus *Nanophyes* has long been in transition, and thus you may find it listed under four different family names. The genus was historically in the weevil family Curculionidae and then was reclassified into the family Brentidae. Various classification systems moved the genus to Apionidae and then back again to the family Brentidae. The genus is currently (as of 2015) recognized as part of the Nanophyidae family. All four families are commonly known as weevils. For more information, key references are provided in the Selected References section.

A related species, *Nanophyes brevis*, was tested and approved for importation but was never released in North America because of problems with parasitism.

Traits and Comparisons

Table 5 shows traits of biological control agents introduced against purple loosestrife in North America, and Table 6 compares biological agent activity in relation to purple loosestrife growth stage.

Table 5. Traits of biological control agents introduced against purple loosestrife in North America

Biological Control Agent	Generations per Year	Overwintering Stage, Location	Adult	Egg	Larva	Pupa
Galerucella calmariensis Black-margined loosestrife beetle	Typically one; two at some locations	Adult in plant litter		Small, spherical; ½ mm wide; white with black line of frass; laid in groups of 2-10 on loosestrife stems and leaves	Greenish-yellow with darkened head capsules, black spots down backs; up to 5 mm long; 3 instars	In soil or (at flooded sites) in spongy tissue of loosestrife stems
Galerucella pusilla Golden loosestrife beetle	Typically one; two at some locations	Adult in plant litter		Small, spherical; ½ mm wide; white with black line of frass; laid in groups of 2-10 on loosestrife stems and leaves	Greenish-yellow with darkened head capsules, black spots down backs; up to 5 mm long; 3 instars	In soil or (at flooded sites) in spongy tissue of loosestrife stems
Hylobius transversovittatus Loosestrife root weevil	Often requires two years for a single generation	Adult in plant litter or larva in roots		White; oval-shaped; laid singly in soil or in loosestrife stems near soil surface	C-shaped; off-white with brown head capsules; up to 10 mm long; 3 instars	In root crown
Nanophyes marmoratus Loosestrife flower weevil	One	Adult in plant litter		Tiny, spherical; white; laid singly in immature flower buds	C-shaped; creamy white with brown head capsules; up to 2 mm long; 3 instars	In the base of attacked buds

Galerucella calmariensis (David Cappaert, Michigan State University; bugwood.org); *G. pusilla* (Eric Coombs, Oregon Department of Agriculture); *Hylobius transversovittatus* (Jennifer Andreas, Washington State University Extension); *Nanophyes marmoratus* (Mark Schwarzländer, University of Idaho; bugwood.org)

Table 6. Comparison of purple loosestrife biocontrol agent activity according to purple loosestrife growth stage (plant and insect stages may vary according to local climate and habitat conditions)

Month	Purple Loosestrife Plant Life Stage	*Galerucella* spp.	*Hylobius transversovittatus*	*Nanophyes marmoratus*
January	Second-year and older plants overwinter as root systems with no growth during this period; seeds are released from senesced flowers	Adults overwinter in plant litter	Larvae overwinter in roots; adults overwinter in plant litter	Adults overwinter in plant litter
February				
March				
April	Seed germination begins; second-year and older plants re-sprout from root system and bolt			
May		Overwintering adults begin laying eggs; larvae begin hatching	Overwintering larvae continue feeding in roots; overwintering adults resume feeding on foliage and lay eggs	Adults emerge and feed on shoot tips and young leaves
June	Plants continue to grow	Larvae continue hatching; pupation begins	New larvae hatch and feed on roots; overwintering adults continue feeding and laying eggs; pupation begins	
July	Flowers form (unless suppressed by insects)	In some locations, adults lay eggs for 2nd generation; elsewhere pupation continues and adults emerge to feed briefly before overwintering	All stages of all generations active	Adults begin laying eggs; larvae begin hatching; pupation begins in buds
August	Flowering continues and seeds mature; in some locations senescence begins, releasing seeds	New adults overwinter in plant litter		
September			Egg-laying and pupation cease; larvae continue to feed; adults prepare to overwinter in plant litter	Egg-laying and pupation cease; new adults prepare to overwinter in plant litter
October	After first extreme frosts, all above-ground parts die back; seeds continue to released		Larvae overwinter in roots where they continue to feed as long as temperatures and flooding allow; adults overwinter in plant litter	New adults overwinter in plant litter
November				
December				

Chapter 4: Elements of a Purple Loosestrife Biological Control Program

Before You Begin

Biological control has led to spectacular suppression of purple loosestrife at many locations in North America. Still, it should be noted that purple loosestrife biological control is not equally effective at all sites for a variety of reasons. Land managers should develop treatment programs that complement land use activities and management objectives unique to the area. This is accomplished by first understanding the scope of the purple loosestrife problem, defining overall goals for the purple loosestrife management program, and understanding the control methods available for accomplishing the goals.

Determining the Scope of the Problem

The first step should be to develop a distribution map of purple loosestrife at a scale that will allow you to address the problem in a manner consistent with your overall land management objectives and your weed management resources. The most appropriate scale may encompass a large landscape with many different land owners/managers, land uses, and site characteristics (Figure 26a). In large management areas with significant purple loosestrife infestations and limited resources, aerial mapping of large patches of purple loosestrife may be sufficient to identify priority areas for additional survey and weed management activities. In other management areas with small, discrete purple loosestrife infestations, or where an infestation's characteristics affect your ability to meet management objectives, your weed management strategy might have to include more extensive mapping and analysis of the scope of the infestations (e.g. size, density, cover, and location in relation to roads and waterways over time) (Figure 26b).

Defining Goals and Objectives

Defining your weed management goals and objectives is crucial to the development of a successful biological control program. By defining what you want to achieve, you will be able to determine if, when, and where you should use biological control.

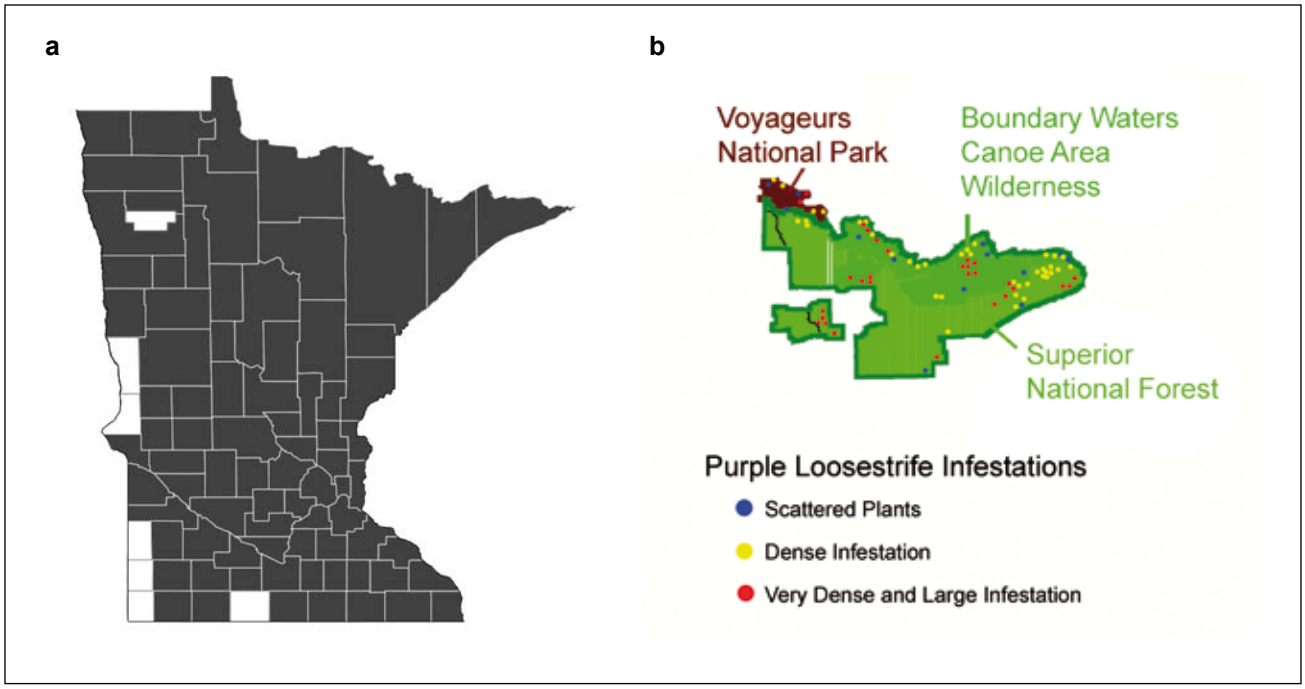


Figure 26. Purple loosestrife data for a. counties with purple loosestrife in the state of Minnesota (EDDMapS); b. hypothetical infestations in select Minnesota parks and forests.

As precisely as possible, you must define what will constitute a successful purple loosestrife management program. For example, the goal of "…a noticeable reduction in purple loosestrife density over the next ten years…" might be achievable, but is subjective and open to observer bias. Alternatively, the goal of "…a 50 percent reduction in purple loosestrife stems over the next three years…" is more precise and measurable. If your goal is to reduce the abundance of purple loosestrife, then biological control is likely an appropriate weed management tool; however, by itself biological control will not completely remove purple loosestrife from the landscape. If your goal is to eradicate purple loosestrife (feasible only for very small patches), then you should plan to employ other weed control techniques instead of, or in addition to, biological control (see Chapter 5 for more details).

In all weed management programs, whether they are biological, physical or chemical, the goal should always be reduction in the *impact* of the targeted plant of agricultural or conservation interests. Sometimes a reduction in a target weed population will achieve that, but not always. Land managers, in collaboration with research scientists need to recognize and wrestle with the need to develop different metrics for success. Acres sprayed is never a good metric, conditions improved for native organisms is. This is not widely recognized and much work needs to be done to develop appropriate metrics, but it will be essential to be accountable for whatever actions land managers and scientists employ for better land stewardship.

Understanding Purple Loosestrife Management Options

Once you determine the scope of your purple loosestrife infestations and define your overall program goals, review the weed control methods available (biological control, physical treatments, cultural practices, and herbicides), and determine the conditions (when, where, if, etc.) under which it might be appropriate to use each method or combination of methods (see Chapter 5). Consult your agency, non-governmental agency, or university biological control expert, cooperative weed management area, or county weed coordinator/supervisor to learn about other purple loosestrife management activities (herbicide use, re-seeding, etc.) underway or planned for your area, and the level and persistence of control that might be achieved by each.

Identify the resources that will be available for weed management activities, and determine if they will be consistently available until you meet your weed management program objectives. If resources are not currently available, or will not be available consistently, identify what will happen at the treatment site if planned management activities are not implemented. This information will help you determine the best management activities to use as you initiate and continue your integrated purple loosestrife management program.

Biological control will help reduce the impact of purple loosestrife in most infestations. With a map of purple loosestrife infestations in your management area, an understanding of your land management goals, well defined weed management objectives, and a list of the weed control methods available with the level of control you can realistically expect from each, you can identify sites where additional weed control methods may complement biological control.

Developing, Implementing, and Managing a Purple Loosestrife Biological Control Program

When biological control is deemed suitable for treating your purple loosestrife infestations, there are several important factors to consider. These include selecting appropriate release sites, obtaining and releasing biocontrol agents, and monitoring the success of the program. Familiarity with all aspects of a biocontrol program before beginning will greatly facilitate its implementation and increase its chances of success. These items are discussed in their own sections below. If problems are encountered following the initiation of a biological control program, refer to the troubleshooting guide in Appendix I for potential solutions.

Selecting Biological Control Agent Release Sites

Establish Goals for your Release Site

You must consider your overall management goals for a given site when you evaluate its suitability for the release of biological control agents.

Suitability factors will differ depending on whether the release is to be a:

1. general release, where biological control agents are simply released for purple loosestrife management,
2. field insectary (nursery) release, which is primarily employed for production of biological control agents for redistribution to other sites, or
3. research release, which is used to scientifically analyze biological control agent biology and/or the agent's impact on the target weed and nontarget plant community.

A site chosen to serve one of the roles listed above may also serve additional functions over time (e.g., biological control agents might eventually be collected for redistribution from a research or general release).

Determine Site Characteristics

For practical purposes, no purple loosestrife infestation is too large for biocontrol releases, provided enough releases are made. However, a patch might not be large enough if it contains only a few isolated plants (Figure 27a). Very small, isolated patches of purple loosestrife may not be adequate for biological control agent populations to build up and persist and may be better treated with other weed control methods, such as physical control. An area with at least ¼ acre (0.10 ha) of purple loosestrife plants is the minimum size to better ensure a successful biological control agent release site, but larger infestations are initially more desirable (Figure 27b), especially if the land manager hopes to someday use the release site as a field insectary. The purple loosestrife infestation does not need to be contiguous, but can be scattered in distant patches (0.6 mile/1 km or less); biological control agents can disperse

Figure 27. Purple loosestrife infestations a. too small for biological control (Leslie J. Mehrhoff, University of Connecticut; bugwood.org); b. appropriate for biological control (Agriculture and Agri-Food Canada; bugwood.org).

easily. In smaller infestations interspersed with desirable plant species, purple loosestrife attacked by biocontrol agents can be outcompeted by more desirable plants quickly. While the loosestrife flower weevil (*Nanophyes marmoratus*) is capable of survival in more sparse, scattered purple loosestrife infestations, the loosestrife leaf beetles (*Galerucella* spp.) quickly build large populations in dense purple loosestrife stands. Choose a site that is in full sunlight (*Galerucella* spp., particularly, prefer full sun). Ideally, select a site that has a moisture gradient from dry to moist: this will allow the beetles to select their preferred moisture levels, and large water fluctuations will not jeopardize the release program. If your biological control program goals involve evaluating the program's efficacy, establish permanent monitoring sites at the beginning of the program. The monitoring sites will require regular inspections, so consider the site's ease of accessibility, terrain, and slope.

Note Land Use and Disturbance Factors

Preferred release sites are those that experience little to no regular disturbances. Fallow sites and natural areas are good choices for biological control agent releases. If a site must be disturbed, the activities should not take place during the spring and summer months (and sometimes winter) when most biological control agents are active above ground. Sites where insecticides are used should not be utilized for biocontrol agent releases. Such sites include those near wetlands that are subject to mosquito control efforts or near agricultural fields that are sprayed regularly. Roadside infestations along dirt or gravel roads with heavy traffic should also be avoided; extensive dust makes plants less palatable to biocontrol agents and silica may kill larvae. Do not use sites where significant conversion will take place, such as road construction, cultivation, building construction, and mineral or petroleum extraction. If supply of biocontrol agents is limited, prioritize release sites that are not regularly burned or treated with herbicides.

Survey for Presence of Biological Control Agents

Examine your prospective release sites to determine if purple loosestrife biological control agents are already present. If a biocontrol agent you are planning to release is already established at a site, you can still release it at that site to augment the existing population, but it may be better to release it at another site. You should re-evaluate the release of the planned species if a different species of biological control agent is present; e.g., *Nanophyes marmoratus* does poorly at sites where high populations of *Galerucella* spp. prevent purple loosestrife plants from flowering.

Record Ownership and Access

If you release biological control agents on private land, it is a good idea to select sites on land likely to have long-standing, stable ownership and management. Stable ownership will help you establish long-term agreements with a landowner, permitting access to the sites to sample or harvest biological control agents and collect insect and vegetation data for the duration of the project. This is particularly important if you are establishing a field insectary site, because five years or more of access may be required to complete insect harvesting or data collection. General releases of biological control agents to control purple loosestrife populations require less-frequent and short-term access; you may need to visit such a site only once or twice after initial release. When releasing biocontrol agents on private land, it may be a good idea to obtain the following:

- written permission from the landowner allowing use of the area as a release site,
- written agreement with the landowner allowing access to the site for monitoring and collection for a period of at least six years (three years for establishment and buildup and three years for collection),
- permission to put a permanent marker at the site, and
- written agreement with the landowner that land management practices at the release site will not interfere with biological control agent activity

The above list can also be helpful for releases made on public land where the goal is to establish an insectary. In particular, an agreement should be reached that land management practices will not interfere with biological control agent activity (e.g. spraying or physically destroying the weed infestation). It is often useful to visit the landowner or land manager at the release site annually to ensure they are reminded of the biological control endeavors and agreement.

You may wish to restrict access to release locations, especially research sites and insectaries, and allow only authorized project partners to visit the sites and collect insects. The simplest approach is to select locations that are not visible to or accessible by the general public. To be practical, most if not all of your sites will be readily accessible, so in order to restrict access you should formalize arrangements with the landowner or manager. This may require you to post no-trespassing signs, install locks on gates, etc. (Figure 28).

Figure 28. Locked gate preventing access to distant biocontrol release sites (Billy Humphries, Forest Resource Consultants, Inc.; bugwood.org).

Another consideration is physical access to a release site. You will need to drive to or near the release locations, so determine if travel on access roads might be interrupted by periodic flooding or inclement weather. You might have to accommodate occasional road closures by private landowners and public land managers for other reasons, such as wildlife protection.

Obtaining and Releasing Purple Loosestrife Biological Control Agents

Many state, federal, and non-governmental agencies will readily provide purple loosestrife biocontrol agents. You can also obtain biological control agents by collecting or rearing them yourself, having someone collect them for you, or by purchasing them from a commercial supplier. This section provides information on collecting, rearing, and purchasing purple loosestrife biocontrol agents, with emphasis on the two *Galerucella* species and *Nanophyes marmoratus*. The loosestrife root weevil, *Hylobius transversovittatus*, is currently more difficult to obtain, though your local weed biocontrol authority will be able to guide you to available laboratory sources.

Factors to Consider When Looking for Sources of Biological Control Agents

You do not need to take a "lottery approach" and release all four biological control agents at a site in the hopes that one of them will work. In fact, the loosestrife root weevil (*Hylobius transversovittatus*) may not be available when you want it, and *Nanophyes marmoratus* does not do

well at infestations with very large *Galerucella* spp. populations. Ask the county, state, or federal biological control experts in your area for recommendations of agents for your particular project.

If available, biological control agents from local sources are best. Using local sources increases the likelihood that biocontrol agents are adapted to the climate and site conditions present and are available at appropriate times for release at your target infestation. Local sources may include neighboring properties or other locations in your county and adjacent counties. Remember: Interstate transport of biological control agents requires a USDA-APHIS-PPQ permit (see Regulations Pertaining to the Transfer of Purple Loosestrife Biological Control Agents, page 58). Get your permits early to avoid delays.

Some states, counties, and universities have "field days" at productive insectary sites (Figure 29). On these days, land managers and landowners are invited to collect or receive freshly collected purple loosestrife biological control agents for quick release at other sites. These sessions are an easy and often inexpensive way for you to acquire biological control agents. They are good educational opportunities as well, because you can often see first-hand the impacts of various biocontrol agents on purple loosestrife plant communities.

Typically, field days are conducted at several sites in a state and on several dates. Although designed for intrastate collection and redistribution, out-of-state participants may be welcome to participate

Figure 29. Purple loosestrife field day (Mark Schwarzländer, University of Idaho; bugwood.org).

(remember that USDA permits are required for interstate movement and release of biological control agents). Contact county weed supervisors, university weed or biological control specialists, or federal weed managers for information about field days in your region.

Collecting Purple Loosestrife Biological Control Agents

Planning and timing of collection is critical. For all species, it is usually most efficient to scout the potential collection site well in advance to ensure your desired species is present and at suitable densities. The species of biological control agent and weather characteristics at your collection and release site will determine the best time in the season to collect. Ensure that all necessary collection supplies are on hand. Also, accurate identification of the biological control agents is essential. General guidelines for collecting purple loosestrife biological control agents are listed below and in Table 7. All purple loosestrife biocontrol agents are most efficiently collected as adults.

For all species, collect only on a day with good weather. Do not collect in the rain; insects will hide and become difficult to find in rainy weather, excess moisture causes health problems, and beetles may drown in wet collection containers. The only exception to this rule is the root feeder *Hylobius transversovittatus*, for which overcast and rainy days are optimal for collecting the generally night-active adults.

Collection methods

Three commonly used methods to collect purple loosestrife biocontrol agents are aspirating, sweep netting, and tap & funnel. The most appropriate method will depend on the density of the insect population, available time, and available personnel.

Table 7. Recommended timetable and methods for collecting purple loosestrife biological control agents in North America. Methods are listed in the order of ease of collection. Collection and activity times may vary by climate and location.

Agent	Insect Stage	Plant Stage	Timing	Method
Galerucella calmariensis and *G. pusilla*	Adults	Stems emerging or before flowering	Mid-May to early June; again from early July to August	Tap & funnel, sweep net, aspirating
Hylobius transversovittatus	Adults	All stages	April to September, peaking from late June to late August	Use sweep net to knock individual beetles into net, or catch beetles dropping off plants; handpick under leaves at ground level
Nanophyes marmoratus	Adults	Stems in bud and early flowering; seeds maturing	Late June to early July; again from mid-August	Sweep net, tap & funnel, aspirating

Aspirating: An aspirator is a device used to suck insects from a surface into a collection vial (Figure 30a). An aspirator is used to collect insects out of a sweep net or off a sorting tray (both described below), though it can also be used to take adults of *N. marmoratus* and *Galerucella* spp. directly from purple loosestrife plants. A variety of aspirators can be purchased from entomological, forestry, and biological supply companies, or you can construct them yourself. For the latter, make sure that tubing reaching your mouth is covered by fine-mesh screening, so that insects and small particles are not inhaled (Figure 30b).

Sweep netting: A sweep net is made of cotton or muslin on a hoop 10 to 15 inches in diameter (25 to 38 cm) attached to a handle 3 feet (0.9 m) long (Figure 30c). They can be purchased from entomological, forestry, and biological supply companies or you can construct them yourself. As their name implies, these are heavy duty nets used to "sweep" insects off purple loosestrife.

A sweep is made by swinging the net through the plant canopy and collecting insects off the foliage. It is best to use no more than 25 sweeps before aspirating the biocontrol agents out of the net. Aspirating or removing insects at regular intervals reduces the potential harm that could result from knocking biocontrol agents around with debris, and reduces the opportunity for predator insects swept up with the biocontrol agents from finding and devouring the agents. It is often helpful to dump the contents of the sweep net into a shallow basin to facilitate aspirating biocontrol agents from debris and other insects in the net.

Sweeping purple loosestrife with a net can be difficult and inefficient because woody stems from previous growing seasons interfere with sweeping the current year's growth (which is where insects are active). A more effective way to use a sweep net is to bend the purple loosestrife

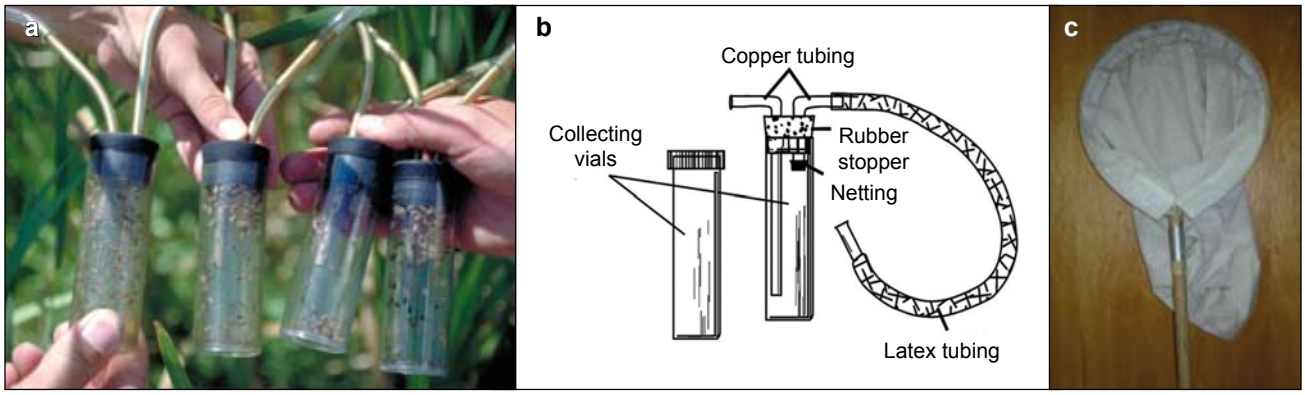


Figure 30. Purple loosestrife biocontrol agent collection methods a. aspirator with *Galerucella* beetles (Gary L. Piper, Washington State University; bugwood.org); b. aspirator diagram (Karen Loeffelman, University of Idaho; bugwood.org); c. sweep net (Laura Parsons, University of Idaho; bugwood.org).

flower inflorescences into the net and shake the plants to dislodge adults into the net. This method works especially well for *N. marmoratus* and when *Galerucella* spp. populations are low.

Tap & funnel: The tap-and-funnel method is an efficient and productive way to collect *Galerucella* spp. and *N. marmoratus* when their populations are high. It is used to gather large numbers of beetles in a short amount of time. Using a stick (a shortened length of broom handle works well) or your hand, knock the beetles from the plants into a funnel taped to a plastic bottle or container (e.g., an empty milk jug or 2-L bottle; Figure 31a,b). Then brush the insects down the sides of the funnel and into the plastic container. Knocking insects into a plastic tray also works, but adults are very active and, in warm weather, will quickly fly away.

Tapping is not selective, so other insects and spiders will be collected along with the biocontrol agents. These insects must be separated from the biocontrol agents before shipping or transporting the biocontrol agents for release to a new site. Cooling the insects before insects are sorted (e.g., for 30 minutes in a refrigerator or cooler) greatly reduces the beetles' activity, and makes sorting much easier. Use an aspirator (described above) to sort the beetles.

Methods by Species

Leaf beetles (*Galerucella* spp.): Adults are easily collected with a funnel or sweep net during the warm part of the day when they are most active. Aspirating is also a suitable, although slower, method for collecting adults. The best time to collect adult leaf beetles is in mid-May to early June, when they have emerged from over-wintering sites and are actively feeding, congregating, and mating. The second period of activity

Figure 31. Tap and funnel a. display; b. being used to collect purple loosestrife biocontrol agents (a,b Martin Moses, University of Idaho; bugwood.org).

occurs from early July to August, when adults of the next generation emerge. Larvae or eggs are not generally collected because of extremely high mortality rates during transportation.

Flower weevil (*Nanophyes marmoratus*): Adults are easily collected by bending and shaking the developing purple loosestrife inflorescences over a sweep net, dislodging the beetles into the net. Aspirating individual adults or mating pairs from plants is possible but slow and laborious. Collect adult beetles during the heat of the day when inflorescences begin to form but before plants begin to flower; mating pairs congregate at the top of these plants and are easily seen. Depending on the location of the site, the collecting period is generally late June to early July, and again from mid-August.

Root weevil (*Hylobius transversovittatus*): This is the most difficult of the purple loosestrife biocontrol agents to collect because it is generally nocturnal or only active on rainy or overcast days. In addition, population numbers are generally low, so field collecting is limited. Where it is possible to collect, do so in the early evening or at night with a flashlight. Weevils are most easily collected by locating an adult on a plant, carefully approaching the plant, placing a sweep net under the stem, and allowing the beetle to drop into the net (they quickly drop from the plant when they sense your presence). Adults can also be collected at the base of the plant by removing the leaf litter and handpicking individual beetles, but this activity is very time-consuming and will only yield good results at high weevil densities. Adults can be collected from late June to late August. (Note: because this species is not widely established at present, it will often be necessary to purchase the weevils from rearing operations until field populations have built up sufficiently to allow collection. See page 54.)

Release Containers for Purple Loosestrife Biological Control Agents

The manner in which biological control agents are handled during transportation to the release site will affect whether they will survive and multiply at the new site. To reduce mortality or injury, it is best to redistribute the biocontrol agents the same day they are collected.

Following collection, biocontrol agents need to be transferred to release containers intended to protect them and prevent them from escaping en route. Release containers should be rigid enough to resist crushing but also ventilated to provide adequate airflow and prevent condensation. Un-waxed paperboard cartons are ideal; they are rigid, permeable to air and water vapor, and are available in many sizes. As an alternative, you can use release containers made of either light-colored lined or waxed paper (e.g., ice cream cartons are particularly suitable, see Figure 32) or

Figure 32. Cardboard release containers for transporting purple loosestrife biocontrol agents (Martin Moses, University of Idaho; bugwood.org).

plastic, providing they are ventilated; simply cut holes in the container or its lid, and cover the holes with a fine mesh screen. Untreated paper bags (lunch bags) work well for transporting biocontrol agents short distances; however, they are fragile and offer little physical protection for the material within, must be sealed tightly to prevent the biocontrol agents from escaping, and some biocontrol agents are capable of chewing through them. *Do not use glass or metal release containers*; they are breakable and make it difficult to regulate temperature, airflow, and humidity.

Fill release containers two-thirds full with crumpled paper towels or tissue paper to provide a substrate for biocontrol agents to rest on and hide in, and to help regulate humidity. Include a few fresh sprigs of purple loosestrife foliage (as food) before adding the biocontrol agents. Purple loosestrife sprigs should be free of seeds, flowers, dirt, spiders, and other insects and should not be placed in water in the release container. Seal the release container lids either with masking tape or label tape. If you are using paper bags, fold over the tops several times and staple them shut. Be sure to label each container with (at least) the biological control agent(s) name, the collection date and site, and the name of the person(s) who did the collecting.

Transporting Purple Loosestrife Biological Control Agents

Keep the Containers Cool at All Times

If you sort and package the biocontrol agents while in the field, place the release containers in large coolers with frozen ice packs. Do not use ice cubes unless they are contained in a separate, closed, leak-proof container. Wrap the ice packs in crumpled newspaper or bubble wrap to prevent direct contact with release containers. Place extra packing material in coolers to prevent ice packs from shifting and damaging

biocontrol agent containers. As an alternative to coolers with ice packs, electric car-charged coolers may be utilized, provided the cycle is set to cool and not warm. Always keep coolers out of direct sun, and only open them when you are ready to remove the biological control agent containers to place them in a refrigerator for overnight storage or to release the biocontrol agents. If you sort and package your agents indoors, keep them in a refrigerator (no lower than 40 °F or 4.4 °C) until you transport or ship them (which should occur as soon as possible but no longer than 48 hours).

Transporting Short Distances

If you can transport your biocontrol agents to their release sites within 3 hours after collection, and release them the same day or early the next, you need not take any measures other than those already described in the previous paragraph.

Shipping Long Distances

You might need to use a bonded carrier service with overnight delivery (e.g., USPS, FedEx, UPS, or DHL) if your release sites are far from your collection sites or you have to deliver your biological control agents to several sites. In such cases, the release containers should be placed in insulated shipping containers with one or more ice packs. Some specially designed foam shippers have pre-cut slots to hold biocontrol agent containers and ice packs (Figure 33a). This construction allows cool air to circulate but prevents direct contact between the ice and the release containers. Laboratory and medical suppliers sell foam "bioshippers" that are used to transport medical specimens or frozen foods. If neither foam product is available, you can use a heavy-duty plastic cooler (Figure 33b).

Figure 33. Shipping biological control agents long distances a. materials needed to ship with a foam shipper; b. shipping with a heavy-duty plastic cooler (a,b Mark Schwarzländer, University of Idaho).

Careful packaging is very important regardless of the shipping container you use. Ice packs need to be wrapped in crumpled newspaper, wrapping paper, or bubble wrap, and should be firmly taped to the inside walls of the shipping container to prevent them from bumping against and possibly crushing the release containers during shipping. Empty spaces in the shipping container should be loosely filled with crumbled or shredded paper, bubble wrap, packing "peanuts," or other soft, insulating material. Use enough insulation to prevent release containers and ice packs from shifting during shipment, but not so much that air movement is restricted. Tape the release container lids shut. Enclose all paperwork accompanying the biocontrol agents (including any needed permits and release forms) before sealing the shipping container. For additional security and protection, you may place the sealed shipping containers or coolers inside cardboard boxes.

Other Factors to Consider

- Make your overnight shipping arrangements well before you collect your biological control agents, and make sure the carrier you select can guarantee overnight delivery.
- Plan collection and packaging schedules so that overnight shipments can be made early in the week. Avoid late-week shipments that may result in delivery on Friday through Sunday, potentially delaying release of the biocontrol agents for several days.
- Clearly label the contents of containers and specify that they are living insects.
- Check with a prospective courier to make sure that they can accept this type of cargo and will not treat the packages in ways that could harm the biological control agents. If the courier cannot guarantee that such treatments will not occur, choose a different carrier.
- Contact personnel at the receiving end, tell them what you are shipping and when it is due to arrive, provide a tracking number, verify that someone will be there to accept the shipment, and instruct them not open the container prior to releasing the biocontrol agents.

Common Packaging Mistakes

Crushing: Secure all material included in the shipping container so that blue ice, bundles of plant material, etc. do not become loose and move around in transit thereby crushing, tearing or popping open release containers and killing or scattering the biocontrol agents inside.

Escape: Tape release containers securely with masking or other easily removable/resealable tape to prevent biocontrol agents from escaping into the shipping container.

Excess heat: Do not expose release containers to direct sunlight or temperatures above 80 °F (27 °C). Avoid shipping delays that can expose biocontrol agents to high temperatures.

Excess moisture: Remove spilled or excess water in release and shipping containers. Do not ship weed sprigs with any type of water source (e.g., floral foam or tubes) inside release containers; use only a small square of new, well rinsed, moist but not damp cellulose sponge. Add crumpled paper towels to release containers to absorb incidental moisture or condensation.

Lack of ventilation: Provide adequate ventilation; use air-permeable release containers or make air holes in plastic containers with push pins or other small diameter tools.

Starvation: Provide sufficient food, and do not store release containers with biological control agents more than 48 hours.

Stress: Provide root-, flower- and seed-free sprigs of the target weed (free also of other weed species' seeds, flowers, dirt, spiders, or other insects) and crumpled paper towels where biocontrol agents can shelter; avoid over-crowding.

Rearing Purple Loosestrife Biological Control Agents

Programs to rear purple loosestrife biocontrol agents have focused primarily on the *Galerucella* leaf beetles because they are relatively simple to rear. Rearing enables large numbers of beetles to be rapidly produced and distributed. In many parts of the United States and Canada, communities, agencies, youth groups, and schools have developed mass rearing programs to help distribute the beetles throughout their states and regions and to provide opportunities for public awareness and education. Numerous examples of these programs can be found throughout the web.

General *Galerucella* and *Nanophyes* Rearing Guidelines

In this guide, we focus on rearing the *Galerucella* leaf beetles. The methods outlined here also work well for *Nanophyes marmoratus*, except that adult weevils are introduced when plants begin to form flower buds (by mid-summer). Rearing *Hylobius transversovittatus* in this manner is not recommended because it is comparatively slow and usually requires highly specialized facilities or a large numbers of plants. Alternatively, *H. transversovittatus* can be reared on an artificial diet (see page 54).

Obtain Plants: In early spring before plants sprout, dig about 100 mature purple loosestrife roots, each with at least five or six stems. Take the roots to your rearing location, and pot them into plastic 1-gallon (3.8 L) pots filled with standard commercial potting mix and a slow-release fertilizer. Place up to 12 pots in a plastic wading pool about 6 feet (2 m) in diameter. Fill the pool with 4 inches (10 cm) of water to simulate a wetland environment (Figure 34). Check the water daily and refill as needed throughout the growing period. If wading pools of the proper size aren't available, construct a pool using pond liner or thick plastic sheeting that can hold water in order to keep plants moist and healthy.

Cover Plants: Place a tomato cage (4-5 feet or 1.2-1.5 m tall) over the pot, and cover the cages with fine mesh netting (no-see-um netting works well). If you intend to rear *N. marmoratus*, these cages will need to be taller, to allow the plants room to develop inflorescences. Secure the top and bottom of the netting with twine, tape or heavy rubber bands; this will keep the beetles in the cage and prevent entry of aphids or other pests and predators that might interfere with plant or beetle growth.

Introduce Beetles: When plants are approximately 1 foot (30 cm) tall, place 10 to 15 *Galerucella* or six to ten *N. marmoratus* beetles in each cage. Be sure to put only one beetle species in each cage. Use only plants that produce an abundance of healthy shoots. Adults will feed for a few days then begin mating and laying eggs. While small at first, *Galerucella* larvae will be obvious in a few weeks. Development from egg to adult takes approximately 30-40 days, and new adult beetles will

Figure 34. Wading pools used to grow purple loosestrife and to rear *Galerucella* spp. (Eric Coombs, Oregon Department of Agriculture; bugwood.org).

begin to appear and congregate near the top of the plants. Larvae of *N. marmoratus* will be concealed inside purple loosestrife buds. Each large plant yields between 500 and 2,000 *Galerucella* beetles or 300 *N. marmoratus* adults. Make sure the newly-emerged adult beetles have sufficient foliage to feed.

Transport Beetles After Rearing: Transport the newly reared beetles in the covered, potted plants to the release site, and place them next to healthy, wild purple loosestrife plants. Make sure the potted plants do not have any immature or mature seeds on them or within the bag or pot. Remove the net bag and the wire cage; gently shake the net bag to dislodge any beetles remaining in the bag. Remove the plant from the pot and rest it on the ground in the infestation; this allows the beetles to disperse on their own. Record the location of the site, the weather conditions at the time of release, and the GPS coordinates of the release site. Use the Sample Biological Control Agent Release Form in Appendix II to record the release. Submit the form to your local weed control authority or land management agency. Keep a copy for your own records.

Overwintering Potted Plants and Beetles: It is quite easy to overwinter beetles outdoors in order to have a large supply for the next year. Retain a portion of the reared beetles on large, caged plants removed from the wading pool. Make sure they have sufficient high-quality food; beetles will feed for a while and disappear into the litter at the base of the plant, where they will remain until spring. To maximize plant and beetle survival, thoroughly mulch and shade the plants throughout the fall and winter. Other elaborate and specialized rearing programs use large cages (Figure 35a) or greenhouses (Figure 35b) to mass-produce adult beetles, but such programs are expensive and labor-intensive.

Figure 35. Alternative rearing methods with mesh-covered purple loosestrife plants: a. cages growing outdoors; b. cages growing in a greenhouse (a,b David Voegtlin, Illinois Natural History Survey; bugwood.org).

Rearing *Hylobius transversovittatus* on an Artificial Diet

An alternative mass rearing method using a semi-artificial diet has been developed for *H. transversovittatus*. While not widely used in weed biocontrol, rearing insects on an artificial diet is a well-established practice in agricultural pest management. The semi-artificial diet, which has the consistency of stiff jelly, is comprised of multiple ingredients, but most importantly contains ground purple loosestrife roots. Root weevil larvae are reared individually on this diet in small containers (Figure 36). They complete development in three months instead of one-to-two years under natural conditions in the field.

Advantages of an artificial diet:

- Development time is reduced from one-to-two years to three months
- Eliminates slow, tedious field collection
- Large numbers of beetles can be reared
- Enables year-round beetle rearing

Disadvantages of an artificial diet:

- Expense
- Requires specialized equipment and skill

See the article by Blossey et al. (2000), cited in the Selected References section, for information on the use of a semi-artificial diet to rear *H. transversovittatus*.

Purchasing Purple Loosestrife Biological Control Agents

A number of commercial suppliers provide purple loosestrife biological control agents. County weed managers, extension agents, or university weed or biological control specialists may be able to recommend one or more suppliers. Make sure that a prospective supplier is reputable,

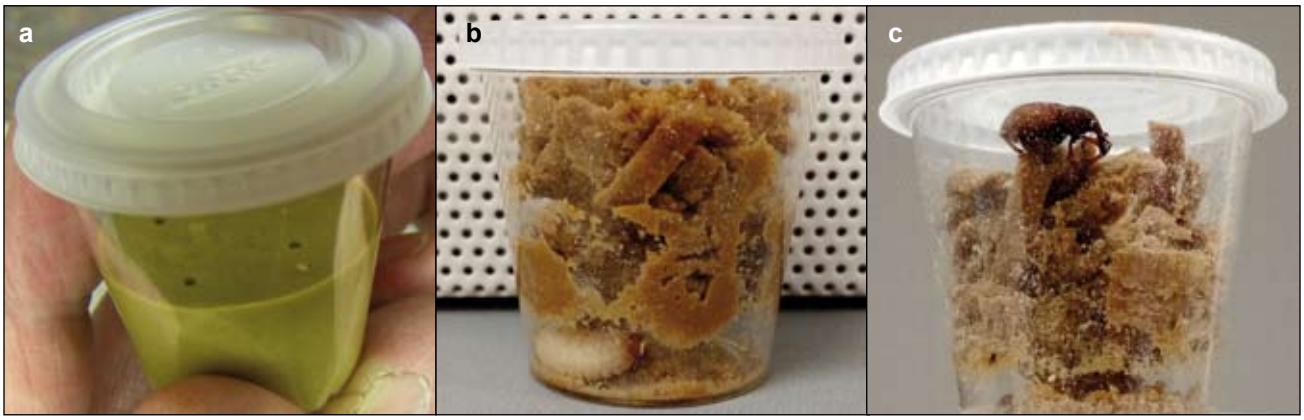


Figure 36. Rearing *Hylobius transversovittatus* on a semi-artificial diet: a. early-instar larva; b. late-instar larva; c. adult (a-c Paul Brusven, Nez Perce Bio-control Center).

can provide healthy individuals of the species you want, and can deliver them to your area at a time appropriate for field release (you will want to know where and when the agents were collected). Interstate shipments of purple loosestrife biological control agents by commercial suppliers also require a USDA permit (see page 58). Confirm in advance that there is a permit in place for the species you are acquiring as well as the region in which the release will occur. DO NOT purchase or release unapproved, non-permitted biological control organisms.

Releasing Purple Loosestrife Biological Control Agents

Establish Permanent Location Marker

Place a steel fence post or plastic/fiberglass pole as a marker at the release point (Figure 37a). Avoid wooden posts; they are vulnerable to weather and decay. Markers should be colorful and conspicuous. White, bright orange, pink, and red are preferred over yellow and green, which may blend into surrounding vegetation. Where conspicuous posts may encourage vandalism, mark your release sites with short, colorful plastic tent/surveyor's stakes or steel plates that can be tagged with release information and located later with a metal detector and GPS.

Record Geographical Coordinates at Release Point using GPS

Map coordinates of the site marker should be determined using a global positioning system device (GPS) or a GPS-capable tablet/smartphone. There are numerous free apps available for recording GPS coordinates on a tablet/smartphone (Figure 37b). Coordinates should complement but not replace a physical marker. Accurate coordinates will help re-locate release points if markers are damaged or removed. Along with the coordinates, be sure to record what coordinate system and datum you are using, e.g., Latitude/Longitude in WGS 84 or UTM in NAD83.

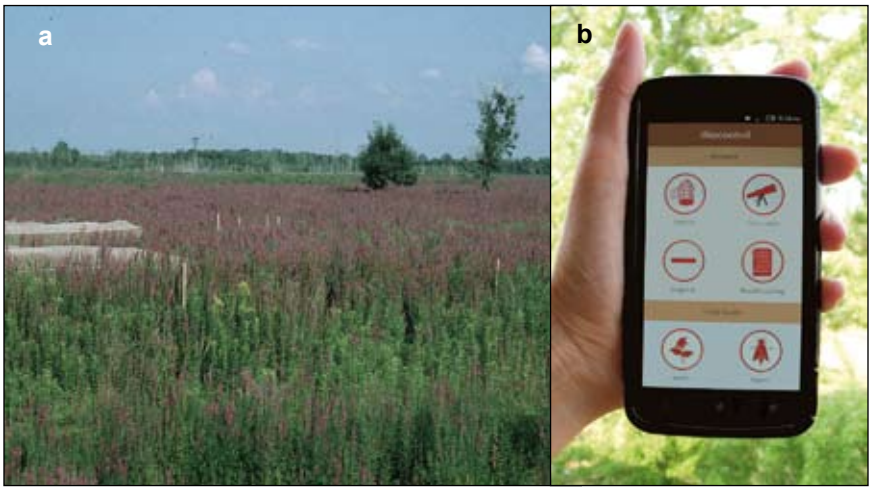


Figure 37. Biocontrol agent release site tools a. permanent markers (Randy Westbrooks, Invasive Species Prevention Specialist; bugwood.org); b. smartphone with free weed and biocontrol agent mapping app iBioControl (Rachel Winston, MIA Consulting).

Prepare Map

The map should be detailed and describe access to the release site, including roads, trails, and relevant landmarks. The map should complement but not replace a physical marker and GPS coordinates. Maps are especially useful for long-term biological control programs in which more than one person will be involved or participants are likely to change. Maps are often necessary to locate release sites in remote locations or places physically difficult or confusing to access.

Complete Relevant Paperwork at Site

Your local land management agency may have standard biocontrol agent release forms for you to complete. Typically, the information you provide includes a description of the site's physical location, including GPS-derived latitude, longitude, and elevation; a summary of its biological and physical characteristics and land use; the name(s) of the biocontrol agent(s) released; date and time of the release; weather conditions during the release; and the name(s) of the person(s) who released the agents (see Sample Biological Control Agent Release Form in Appendix II). The best time to record this information is while you are at the field site. Consider using a smartphone and reporting app such as iBioControl. This free application uses EDDMapS (see page 60 for more information) to help county, state, and federal agencies track releases and occurrences of biological control agents of noxious weeds. Once back in the office, submit the information to your local weed control office, land management agency, or other relevant authority/database. Keep a copy for your own records.

Set Up Photo Point

A photo point is used to visually document changes in purple loosestrife infestations and the plant community over time following the release of biocontrol agents. Use a permanent feature in the background as a reference point (e.g., a mountain, large rocks, trees, or a permanent structure) and make sure each photo includes your release point marker. Pre- and post-release photographs should be taken from roughly the same place and at the same time of year. Label all photos with the year and location.

Release as Many Agents as Possible

As a general rule of thumb, it is better to release many individuals of a biocontrol agent species at one purple loosestrife infestation than it is to spread those individuals too thinly over multiple purple loosestrife infestations. Releasing all the agents within a release container in one spot will help ensure that adequate numbers of males and females are present for reproduction and reduce the risks of inbreeding and other genetic problems. If you have more than one release container, be sure to put some distance between the two releases; 1 km (2/3 mile) is ideal.

- *Galerucella* spp.: It is possible to collect several thousand beetles, thus a release of 1,000 beetles is recommended; however, even releases of 200 adults in the spring have yielded good results. When collecting from the summer generation, a minimum release of 2,000 *Galerucella* spp. adults is recommended.
- *Nanophyes marmoratus*: At high densities, it is possible to collect several hundred beetles in an hour. A minimum release of 200 adults per site is recommended. Avoid releasing at sites where high populations of *Galerucella* spp. are present.
- *Hylobius transversovittatus*: It is more difficult to obtain this biocontrol agent, but a release of at least 100 adult beetles is recommended.

In general, you can release biocontrol agents either in cages (Figure 38a) or open releases. Caged releases prevent immediate dispersal of biocontrol agents but require you to put up and take down equipment. For open releases, get to the desired release location, open the release container, and gently shake out all insects and purple loosestrife stems and foliage in one small area. Do not scatter biocontrol agents throughout the infestation. Make sure the purple loosestrife stems in the release container do not have any immature or mature seeds on them before releasing at the new site. Gently dislodge any beetles hiding in or clinging to the paper towels in the release containers (Figure 38b). Do not release over water, but at the shore or on dry land if possible. For caged releases, place a mesh bag over a purple loosestrife plant, release insects into the caged plant, and tie the bottom of the bag to the stem. Cages confine the insects for a period of time so they adjust to the site and easily find one another, but cages should be removed in a timely manner.

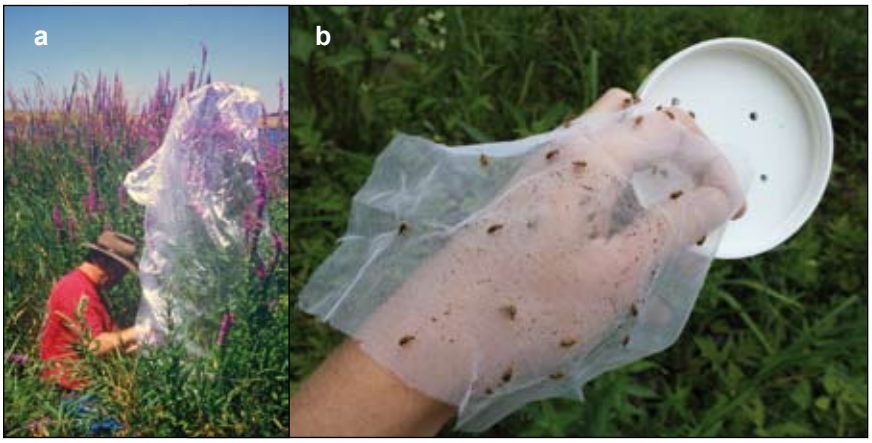


Figure 38. Releasing purple loosestrife biocontrol agents a. in cages (Eric Coombs, Oregon Department of Agriculture; bugwood.org) and b. in the open, dislodging any individuals clinging to the release substrate (Caitlin Stewart, Hamilton County Soil & Water Conservation District, New York).

Releases of all biocontrol agents should be made under moderate weather conditions (mornings or evenings of hot summer days, mid-day for cold season releases). These times prevent dispersal flights of the stressed individuals when released from confinement, which would prevent them from establishing. If you encounter an extended period of poor weather, however, it is better to release the insects than wait three or more days for conditions to improve as the biocontrol agents' vitality may decline with extended storage. Avoid transferring biocontrol agents to areas with a number of ant mounds or ground dwelling animals that may prey upon the biological control agents.

Regulations for the Transfer of Purple Loosestrife Biological Control Agents

USA, intrastate: Generally, there are few if any restrictions governing the collection and shipment of approved biological control agents within the same state; however, you should check with your state's department of agriculture or agriculture extension service about regulations governing the release and intrastate transport of your specific biological control agent. The state of California regulates release permits at the county level.

USA, interstate: The interstate transportation of biological control agents is regulated by the U.S. Department of Agriculture (USDA), and a valid permit is required to transport living biological control agents across state lines. You should apply for a Plant Protection and Quarantine (PPQ) permit from the Animal and Plant Health Inspection Service (APHIS) as early as possible—but at least six months before actual delivery date of your biological control agent. You can check the current status of regulations governing intrastate shipment of weed biological control agents, PPQ Form 526 at the USDA-APHIS-PPQ website. The ePermit process can be accessed by doing an internet search for "USDA APHIS 526 permit application". This allows the complete online processing of biological control agent permit requests.

Canada: Canada requires an import permit for any new biological control agent or shipments from overseas of previously released agents. Permits are issued by the Plant Health Division of the Canadian Food Inspection Agency. Redistribution within a province (or even within Canada) of weed biological control agents that have been officially approved for use in Canada is generally allowed; however, you should consult with provincial and federal authorities and specialists prior to moving any weed biological control agent between areas (e.g., from the prairies to the interior or coast of British Columbia). Accidentally introduced biocontrol agents that have become adventive in a region, or native organisms that may feed on a weed targeted for control should not be moved to new areas without consulting federal authorities and specialists as their host range or potential ecological impacts are not fully known.

Documenting, Monitoring, and Evaluating a Biological Control Program

The Need for Documentation

The purpose of monitoring is to evaluate the success of your purple loosestrife biological control program and to determine if you are meeting your weed management goals. Documenting outcomes (both successes and failures) of biocontrol release programs will help generate a more complete picture of biocontrol impacts, guide future management strategies, and serve education and public relations functions. Monitoring can provide critical information for other land managers by helping them predict where and when biological control might be successful, helping them avoid releasing ineffective biocontrol agents or the same biocontrol agent in an area where they were previously released, and/or helping them avoid land management activities that would harm local biocontrol agent populations or worsen the purple loosestrife problem. (See the Code of Best Practices for Classical Biological Control of Weeds on page 5.)

Monitoring activities utilize standardized procedures over time to assess changes in populations of the biocontrol agents, purple loosestrife, other plants in the community, and other components of the community. Monitoring can help determine:

- If the biological control agents have become established at the release site
- If biological control agent populations are increasing or decreasing and how far they have spread from the initial release point
- If the biological control agents are having an impact on purple loosestrife
- If/how the plant community or site factors have changed over time

Monitoring methods can be simple or complex. A single year of monitoring may demonstrate whether or not the biocontrol agents established, while multiple years of monitoring may allow you to follow the population of the biocontrol agents, the decline of the target weed, changes in the plant community, and changes in other factors such as climate or soil.

Information Databases

Many federal and state agencies have electronic databases for archiving information from biological control releases. We have included a standardized biological control agent release form that, when completed, should provide sufficient information for inclusion in any number of databases (see Appendix II).

At the federal level, the USDA Animal and Plant Health Inspection Service (APHIS) maintains the Cooperative Agricultural Pest Survey (CAPS) database, which is part of the National Agricultural Pest Information System (NAPIS). Biological control agent release information is entered into CAPS by a number of state and federal agency personnel who serve on the state's CAPS survey committee. Contact your local APHIS officials or state department of agriculture for more information on participation.

The USDA Forest Service maintains a database of biological control agent releases on federal and non-federal lands. As of the writing of this document, weed biocontrol agent releases made on Forest Service lands are entered into the Forest Service ACtivity Tracking System (FACTS) database. Other agencies may maintain their own databases for this information. Many of the databases maintained by state and federal agencies have safeguards in place to prevent undesirable uses of the information they contain.

The USDA Forest Service (in conjunction with the University of Georgia, MIA Consulting, University of Idaho, CAB International, and the Queensland Government) also maintains a worldwide database for the Biological Control of Weeds: A World Catalogue of Agents and their Target Weeds. The database includes entries for all weed biocontrol agents released through to date, including the year of first release within each country, the biocontrol agents' current overall abundance and impact in each country, and more. This database can be accessed at www.ibiocontrol.org/catalog/.

EDDMapS (Early Detection & Distribution MAPping System) is a web-based mapping system increasingly being used for documenting invasive species as well as biocontrol agent distribution in North America. EDDMapS combines data from existing sources (e.g. databases and organizations) while soliciting and verifying volunteer observations, creating an inclusive invasive species geodatabase that is shared with educators, land managers, conservation biologists, and beyond. Information can be added in online forms through home computers and/or apps created for smartphones. For more information on how to utilize or contribute to these tools, visit www.eddmaps.org/about/ and apps.bugwood.org/.

Monitoring Methods

There are three main components to measure in a purple loosestrife monitoring program: biological control agent populations, purple loosestrife populations, and the rest of the plant community (including nontarget plants). More detailed monitoring might also examine effects on other biotic community components (such as other insects, birds, mammals, etc.) or abiotic factors (such as erosion, soil chemistry, etc.). Only the three main monitoring components are discussed in this manual.

Assessing Biological Control Agent Populations

If you wish to determine whether or not purple loosestrife biocontrol agents have established after initial release, you simply need to find the biocontrol agents in one or more of their life stages, or evidence of their presence (Table 8). Begin looking for biocontrol agents where they were first released, and then expand to the area around the release site.

Populations of some biocontrol agents take two or more years to reach detectable levels. Thus if no biocontrol agents are detected a year after release, it does not mean they failed to establish. Revisit the site at least once annually for three years. If no evidence of biocontrol agents is found, either select another site for release or make additional releases at the monitored site. Consult with your county extension educator or local biological control of weeds expert for assistance.

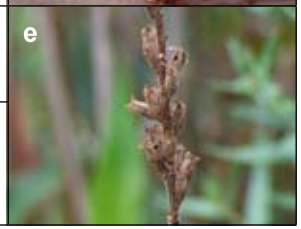
To determine the changing densities of biocontrol agent populations, a systematic monitoring approach is needed. The Cornell University Purple Loosestrife Monitoring Protocol is one such approach to monitoring biocontrol agent populations, weed populations, and the surrounding plant community over time (Appendix III). This protocol was developed by Bernd Blossey and Victoria Nuzzo in collaboration with many land managers and is widely used throughout the eastern United States. It was designed to be simple, efficient, and sufficiently versatile to allow for the collection of information from the same sites over multiple years. You can easily modify these protocols to meet your personal or agency needs. An alternative general biological control agent monitoring form can be found in Appendix IV.

Assessing the Status of Purple Loosestrife and Co-occurring Plants

The ultimate goal of a purple loosestrife biological control program is to reduce the abundance of purple loosestrife and enable the recovery of more desirable vegetation on the site. To determine the efficacy of biocontrol efforts, there must be monitoring of plant community attributes, such as target weed distribution and density. Ideally, monitoring begins before biological control efforts are started (pre-release) and at regular intervals after release. There are many ways to qualitatively (descriptively) or quantitatively (numerically) assess weed populations and other plant community attributes at release sites.

Qualitative (descriptive) vegetation monitoring: Qualitative monitoring uses subjective measurements to describe the purple loosestrife and the rest of the plant community at the management site. Examples include listing plant species occurring at the site, estimates of density, age and distribution classes, visual infestation mapping, and maintaining a series of photos from designated photo points (Figure 39a,b). See Appendix V for a sample data form where you can record qualitative toadflax monitoring data along with information

Table 8. Life stages/damage to look for to determine establishment of purple loosestrife biological control agents: a. *Galerucella* spp. adult shot-hole feeding on a leaf (Eric Coombs, Oregon Department of Agriculture; bugwood.org); b. *Galerucella* spp. larval window-pane feeding on a leaf (Bernd Blossey, Cornell University; bugwood.org); c. *Hylobius transversovittatus* adult feeding damage on a leaf (Eric Coombs, Oregon Department of Agriculture; bugwood.org); d. *H. transversovittatus* larval damage to roots (Bernd Blossey, Cornell University; bugwood.org); e. Buds with adult exit holes and 100% abortion due to feeding by *Nanophyes marmoratus* larvae and adults (S. Schooler, Oregon State University; bugwood.org).

Agent	Life Stage	Where to Look	When to Look	Damage	Damage Appearance
Galerucella calmariensis and *G. pusilla*	Adults	Feeding or ovipositing on leaves and stems in spring; feeding on leaves/stems in late summer	Spring/Summer (May-Jul)	"Shot hole" defoliation pattern	 a
	Larvae	Leaves, stem tips	Early to Late Summer (May-Jul)	Leaves with bottom layers fed upon; upper leaf cuticle and epidermis intact, creating a "window-pane" effect	 b
Hylobius transversovittatus	Adults	Stems and leaves; ovipositing females in soil or at base of loosestrife plants	Spring-Fall (Apr-Sep)	Chewed leaves with feeding around edges	 c
	Larvae	Within roots	Year-round	Mines (tunnels) within roots, often filled with light brown frass	 d
Nanophyes marmoratus	Adults	Feeding on or ovipositing in floral buds	Summer (May-Sep)	Buds with chewed sides; exit holes	 e
	Larvae	Within floral buds	Late Spring-Summer (late Jun-Sep)	Buds with chewed-out interiors	

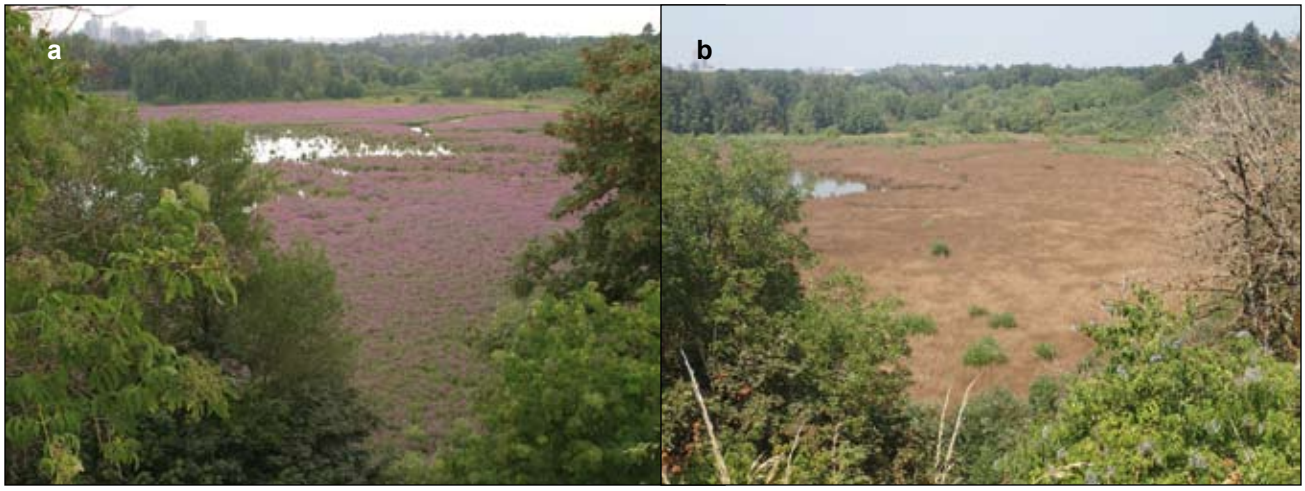


Figure 39. Purple loosestrife infestation a. before (2007) control by *Galerucella* beetles (Colin Park, USDA APHIS PPQ); b. after (2015) control by *Galerucella* beetles (Marc Peters, City of Portland).

on associated vegetation. Qualitative monitoring provides insight into the status or change of purple loosestrife populations. However, its descriptive nature does not generally allow for detailed statistical analyses. Data obtained in qualitative monitoring may trigger more intensive monitoring later.

Quantitative vegetation monitoring: The purpose of quantitative monitoring is to measure changes in the purple loosestrife population as well as the vegetative community as a whole before and after a biocontrol agent release. It may be as simple as counting the number of purple loosestrife stems in a small sample area, or as complex as measuring purple loosestrife plant height, flower and seed production, biomass, species diversity, and species cover (Figure 40). If designed properly, quantitative data can be statistically analyzed and give measurable information on plant community changes. Pre- and post-release monitoring should follow the same protocol and be employed at the same time of year. Post-release assessments should be planned annually for at least three to five years after the initial biocontrol agent release.

See Appendix VI for a sample data form where you can record quantitative purple loosestrife monitoring data along with data on associated vegetation. The Cornell University monitoring protocol described earlier and found in Appendix III is a combination of qualitative and quantitative elements as well as counts for biological control agents. This approach can be easily modified to meet your personal or agency needs.

Figure 40. Estimating purple loosestrife coverage (Doug Landis, Michigan State University; bugwood.org).

Assessing Impacts on Nontarget Plants

To address possible nontarget attacks on species related to purple loosestrife, you must become familiar with the plant communities present at and around your release sites and be aware of species related to purple loosestrife (see again Tables 2 and 3 in Chapter 2). You may have to consult with a local botanist or herbarium records for advice on areas where nontarget plants might be growing and additional information on how you can identify them. Care should be taken in the management of your purple loosestrife biocontrol program to ensure that all closely related native species are identified and monitored along with purple loosestrife.

If you observe approved biocontrol agents feeding on and/or developing on nontarget species, the vegetation sampling procedures described above can be easily modified to monitor changes in density and/or cover of the nontarget species. Concurrently, you may wish to collect additional data, such as the number of agents observed on nontarget plants, the amount of foliar feeding observed, or the presence of characteristic biocontrol agent damage. Collecting this data for subsequent years can help determine if there is a population level impact or if the nontarget feeding is temporary or of minor consequence to the nontarget species. Please be aware that there are many "look-alike" native insects (particularly for the leaf beetles *Galerucella* spp.) that may feed on related native plants. Correct identification by insect specialists is needed to confirm such records. Species have been misidentified on several occasions.

If you observe approved biological control agents feeding on and/or developing on native plant species, collect samples and take them to a biocontrol specialist in your area. Alternatively, you may send the specialist the site data so he or she can survey the site for nontarget impacts. Be sure not to ascribe any damage you observe on native species to any specific insect and thus bias the confirmation of attack and the identification of the species causing the attack.

Chapter 5: An Integrated Purple Loosestrife Management Program

Introduction

Classical biological control has been applied to many invasive weed species, and there are several examples in which both single- and multiple-biocontrol agent introductions have successfully controlled the target weeds. Purple loosestrife biocontrol agents, in particular, have provided spectacular control throughout North America. At many locations, biological control alone successfully maintains purple loosestrife densities below economically significant levels, enabling land managers to live with the weed. However, it may take three to five years or more for biological control to reduce weed populations to such manageable levels. Furthermore, purple loosestrife occurs across a wide range of conditions, and some locations are unsuitable to biocontrol agents. Consequently, biological control is not going to work against purple loosestrife every time at every site. Biocontrol agents have difficulties establishing and reducing purple loosestrife in tidal rivers and estuaries or in partially or fully shaded wetlands, but these are the exceptions. In many instances, patience and potential re-releases if biocontrol agents do not establish the first time are appropriate actions to consider. But depending on the infestation, integration with other weed control methods may be required to attain purple loosestrife management objectives. A variety of weed control methods have been developed and may be useful for helping meet management goals for purple loosestrife. Many successful long-term purple loosestrife management efforts have a number of common features, including:

- Education and Outreach
- Inventory and Monitoring
- Prevention
- Weed Control Activities: A variety of purple loosestrife control activities which are selected based on characteristics of the target infestation and planned in advance to use the most appropriate method or combination of methods at each site, including:
    - Biological control
    - Physical treatment
    - Cultural practices
    - Chemical treatment

Programs which incorporate many of these activities are called Integrated Weed Management (IWM) programs, and they address several aspects of land management, not just weed control. Land managers or landowners engaged in IWM take the time to educate themselves and others about the threat invasive plants pose to the land. They get out on their land and look for potential threats, including purple loosestrife. When an infestation is found, they map it and make plans to address it utilizing control methods most appropriate for their particular infestation. After initiating control activities, they monitor if the control was successful. If re-treatment or additional treatments are necessary, these are applied in a timely manner with appropriate post-treatment monitoring to ensure that management objectives are being met.

The components of purple loosestrife IWM are described individually below. Because the focus of this manual is the biological control of purple loosestrife, the potential to integrate biocontrol with other weed control methods is described at the end of each control method's section. Long-term management success is greatly improved when control methods are identified according to infested habitat type, land use, ownership, and available resources and then integrated if appropriate.

Components of Successful Integrated Weed Management Programs to Manage Purple Loosestrife

Education & Outreach

Education and outreach activities increase public awareness of noxious weeds, the problems they cause, their distribution, and ways to manage them. Ideally, education and outreach activities also foster cooperation and collaboration across land ownership boundaries to facilitate the development of a landscape-level weed management response. Education efforts should be an important component of any weed management plan, regardless of the target weed or weed control method employed.

Purple loosestrife education and outreach should focus on conveying to the public:

- the threat purple loosestrife poses (Figure 41)
- how to identify purple loosestrife in different stages
- the importance of not utilizing/planting purple loosestrife or any of its cultivars in any setting (including as an ornamental, or in and around wetlands)
- ways in which they can help in purple loosestrife management

By educating land managers and landowners, recreationalists, and the public about the threat of purple loosestrife, enabling them to identify infestations, and enlisting them in mapping and management efforts, it becomes possible to cooperatively develop successful weed management responses at the landscape scale.

Figure 41. Purple loosestrife education poster (Marion County Oregon Weed Control District).

Inventory & Mapping

Inventory and mapping are key elements of a successful weed management program. It is imperative that the extent of a weed population be understood before control activities are identified, prioritized, and implemented because the best treatment methods are often determined by the size and location of the infestation. Education and outreach activities that foster collaboration between adjacent landowners are particularly useful when developing landscape-level maps of weed infestations. As land managers and landowners gain an appreciation for the threat purple loosestrife poses to their land, they are often more willing to participate to ensure that their land is inventoried and accurate maps of purple loosestrife are developed so the best control activities can be implemented. When purple loosestrife infestations are identified, areas downstream from river or creek infestations and on all sides of a lake or pond infestation should be monitored for purple loosestrife establishment.

Purple loosestrife infestations are often mapped by foot, vehicle, horse, boat, or airplane using a global positioning system unit (GPS) and a geographical information system (GIS), though hard copy maps made by

hand are suitable for some locations. An exciting recent development is the increasing use of free smartphone and tablet apps that make accurate, detailed, and versatile weed mapping available to anyone (e.g. the apps available from EDDMapS; see page 60 for more information). Inventory efforts should document the following for each infestation: location, boundaries, estimated density (number of loosestrife stems per unit area), land usage, treatment history, and date. Photos of the infestation and a list of co-occurring species are also useful. Documenting inventory and mapping efforts enables land managers to determine if all known purple loosestrife infestations have been treated, and facilitates post-treatment monitoring. In turn, this allows land managers to judge the effectiveness of various treatment methods. See Chapter 4 for suggested techniques of monitoring infestations.

Prevention

Prevention activities focus on areas not currently infested by purple loosestrife with the goal of keeping these areas weed-free. Though purple loosestrife is already present throughout much of North America, there are many sites where it is absent or remains at low densities. Inventory efforts help identify the precise borders of these locations. Preventing introduction and spread of purple loosestrife to uninfested areas is more environmentally desirable and cost-effective than is treatment of large-scale infestations.

Purple loosestrife is spread by the movement of seed-contaminated water, hay, wind, motorized equipment, livestock, wildlife, or root-fragments into uninfested areas. Preventing the spread of purple loosestrife requires cooperation among all landowners and land managers. In areas where purple loosestrife is not yet present, it is important to ensure that possible invasion avenues are identified and management actions taken to reduce the risk of spread. This includes minimizing soil disturbances and regularly monitoring uninfested sites to ensure they remain uninfested.

Soil disturbances along water bodies, such as those caused by construction, overgrazing/trampling, and recreational activities (e.g., riding dirt bikes or four wheelers through streambeds, Figure 42) all weaken existing plant communities, decrease plant cover, and create bare patches of soil, conditions that favor purple loosestrife establishment and persistence. Such activities are also potential sources of spreading purple loosestrife seeds, and they should be avoided in purple loosestrife-prone areas. If it is not possible to avoid driving vehicles and machinery (e.g., boats and construction equipment) through purple loosestrife infestations, it is crucial that a thorough cleaning take place before vehicles and equipment leave the contaminated area.

Figure 42. Streambed soil disturbance caused by recreationalists (Tovio).

Prevention and exclusion activities are typically paired with education efforts. Examples of exclusion efforts include state and provincial seed laws and mandatory equipment/vehicle cleaning when leaving infested sites and before entering uninfested sites. Because purple loosestrife is still sold and planted for its beauty as an ornamental (often illegally), points of sale should be monitored frequently to ensure purple loosestrife and supposed related species are not being sold. Refer to the comments in Chapter 2 of this manual for further information.

EDRR

An early detection and rapid response (EDRR) program is a specific protocol for tracking and responding to new infestations. It relies heavily on education and outreach activities to be effective. An EDRR program targets areas where purple loosestrife may spread. It consists of three complementary activities: 1) educating land managers and the public on weed identification and mapping techniques, 2) enlisting their aid in immediate and thorough detection of the weed, and 3) initiating rapid response eradication efforts at all verified locations of the weed.

Weed Control Activities

Biological Control

Biological control involves the use of living organisms, usually insects, mites, or pathogens, to control a weed infestation and recreate the balance of plant species with their natural predators and pathogens. Classical biological control focuses on the introduction of select natural enemies from the invasive weed's site of origin. Biological control has proven very effective for suppressing purple loosestrife infestations throughout North America. Though it is successfully applied in a variety

of habitats, it is not equally effective in all locations and is most suitable for infestations with at least ¼ acre (0.10 ha) of purple loosestrife. Very small, isolated patches of purple loosestrife may be better treated with other weed control methods, such as physical or (if practicing extreme caution) chemical control. Refer to Chapter 3 for detailed descriptions of the biological control agents currently approved for use against purple loosestrife and Chapter 4 for how to implement a biological control program in your area.

Physical Treatment

Physical treatment utilizes hand pulling, clipping, tilling, or mowing to remove or disrupt the growth of weeds and is the oldest method of weed control. Physical methods have largely been unsuccessful in controlling purple loosestrife, are labor intensive, and are not suitable for much of the sensitive wetland areas purple loosestrife has invaded. Because tilling and mowing are likely to spread plant and root fragments or seeds, they are not recommended for purple loosestrife control. Hand pulling and clipping are applicable only for very small and easily accessible purple loosestrife infestations where repeated treatments are possible.

Hand pulling

Hand pulling (Figure 43a) may be successful on very small patches of purple loosestrife if applied persistently. Should the purple loosestrife infestation increase, biological control efforts should be initiated. Hand pulling is most effective on young plants (if they can be correctly identified) growing in wet and/or loose soil. As plants age, or for plants growing in compacted soils, hand pulling can result in increased purple loosestrife populations due to seedling recruitment in the newly disturbed soil and occasionally by regeneration from the severed roots of pulled plants. Consequently, it is important to remove as much of the purple loosestrife root as possible, while minimizing soil disturbance. The seedbank in established purple loosestrife infestations is capable of producing new purple loosestrife stands for years after weed control activities. To account for this, purple loosestrife infestations should be hand pulled several times a year for multiple years. When purple loosestrife plants are in flower or seed, cut off and bag all flower stalks prior to pulling. Otherwise, the jarring action of pulling may dislodge and distribute seeds at the site. All roots, stems, flowers and seeds should be securely bagged and taken to the trash or a transfer site to prevent possible purple loosestrife vegetative growth or seed dispersal from pulled material. Re-seeding the open space resulting from purple loosestrife removal with seeds of desirable vegetation can provide competition to decrease purple loosestrife seedling germination and persistence.

Due to the destructive nature of hand pulling, this control method is not compatible with biological control. Keep in mind, however, that hand pulling is most appropriate for very small infestations where immediate eradication is feasible, while biological control is appropriate for more established infestations. One way to successfully combine these two methods is to release biological control agents in a large, main infestation while employing hand pulling to control small satellite infestations surrounding the main infestation.

Clipping

Removing flowering stems by clipping may reduce seed production. However, this does not kill the clipped plants, and so clipping must be repeated regularly. Clipping is most effective when done late in the season but prior to seed set (Figure 43b). Many clipped stems are likely to re-sprout the same year, so multiple follow up treatments are warranted. All roots, stems, flowers and seeds should be securely bagged and taken to the trash or a transfer site to prevent possible purple loosestrife vegetative growth or seed dispersal from cut material.

At sites where *Galerucella* spp. and/or *Hylobius transversovittatus* are present, purple loosestrife stems should be clipped late in the season but prior to seeding. Clipping is not compatible with the flower weevil, *Nanophyes marmoratus*.

Cultural Practices

Cultural methods of weed control, including burning, grazing, flooding, and seeding with competitive species, can enhance the growth of desired vegetation, which may slow the invasion of noxious weeds onto a site. Regardless of which method is used, all cultural control techniques are

Figure 43. Physical control of purple loosestrife: a. digging up plants in moist soil; b. clipping flowering stems (a,b Jennifer Andreas, Washington State University Extension).

more successful when combined with other control methods (biological, physical, or chemical control).

For purple loosestrife management, burning is largely considered ineffective due to the moist conditions present at infestations and to the amount of moisture retained in purple loosestrife stems, even where stems are clipped prior to burning. Grazing has also been dismissed as generally ineffective. A recent study achieved a reduction in purple loosestrife and an increase in species diversity following targeted rotational grazing with sheep for a single season; however, the long-term effects of this practice are unknown. In most conventional grazing systems, the stocking rate and rotational times are not in line with the study, and have been shown to exacerbate the purple loosestrife problem after livestock feed on desirable species and create more disturbance conducive to purple loosestrife colonization.

Flooding

Flooding is not a preferred method for managing purple loosestrife. Flooding infested areas for extended periods of time in spring and early summer may inhibit purple loosestrife seedling establishment, especially if purple loosestrife plants cannot germinate. Over multiple years of flooding, purple loosestrife stands may be eliminated. Flooding is unlikely to affect established purple loosestrife plants, however, which can survive deep-water conditions if growing even partially emerged (Figure 44). If flooding is successfully used against the weed, it is likely purple loosestrife seedlings will recolonize the bare soil once the water levels recede. Most importantly, flooding may be just as detrimental to desirable vegetation as it is to purple loosestrife.

Figure 44. Purple loosestrife growing in standing water (Caitlin Stewart, Hamilton County Soil & Water Conservation District, New York).

Flooding can be successfully combined with biological control, provided it is done in spring and early summer when most stages of biocontrol agents are active in the foliage and flowers of purple loosestrife. The adults of *Nanophyes marmoratus* and the pupae and adults of *Galerucella* spp. would be killed by flooding performed in late summer or in the winter. *Hylobius transversovittatus* are much more tolerant of extended flooding, provided the site is not flooded permanently year-round.

Seeding Competitive Species

Where purple loosestrife is established and then suppressed by one or more control methods, reinvasion by purple loosestrife (or other undesirable species) is likely if the ecological niche it occupied remains unfilled. Successful long-term management requires the establishment and maintenance of desirable competitive species to avoid reinvasions.

Purple loosestrife plants are sensitive to competition for light and resources during early growth stages. Though studies have shown that planting competitive species can successfully reduce purple loosestrife establishment, most of this work was conducted with exotic replacement species that could prove as detrimental as purple loosestrife in the long run. Studies utilizing native species are generally lacking. Consequently, the most suitable species and methods to use in re-seeding are largely unknown, and will likely vary by habitat, site conditions, climate, management goals, and future land use. Ideally, planted seeds should contain a mix of species, some of which should be quick to germinate and others to provide more long-term competition to purple loosestrife seedlings. Utilizing ecologically equivalent species (those with root and growth patterns similar to purple loosestrife) may provide the best competition. Inventorying nearby sites that are uninvaded by purple loosestrife may provide insight into the best replacement species. Consult your local county extension agent or Natural Resource Conservation Service (NRCS) representative for additional help in determining the best alternatives in your area. Further suggestions for ecoregions throughout the United States may be found on the Native Seed Network website (please see Chapter 5 References for the URL). Likewise, the “links” section of the USDA PLANTS website offers numerous revegetation guideline manuals specific to different regions of both the United States and Canada. This site also provides access to a program and fact sheets that utilize soil, plant, and climate data to select plant species that are site-specifically adapted, suitable for the selected practice, and appropriate for the goals and objectives of the revegetation project.

Control of purple loosestrife prior to seeding more desirable species is important because established loosestrife plants are highly competitive. Seeding of competitors should take place immediately following

exposure of soil to maximize their competitive abilities. For example, seeding should occur in bare soil after young loosestrife plants have been hand pulled. Because high populations of rodents can reduce the success of re-seeding, erecting a raptor perch/pole may discourage rodent habitation and help ensure seeded species successfully germinate and establish.

Incorporating biocontrol agents with re-seeding has not been studied, though it is likely to prove compatible where competitive species are successfully established, and then biocontrol agents are introduced to help control any purple loosestrife plants that re-grow. In other settings, it may be the biological control agents that open up the competing plant canopy, allowing for subsequent re-seeding to occur.

Chemical Control

Although herbicides (Figure 45) have long been used in the management of invasive plants, this form of weed control has only limited application against purple loosestrife.

Herbicide usage is most effective on very small infestations, including newly established populations and recently established satellite patches arising from nearby older, larger purple loosestrife infestations. Herbicides have been touted for use on the leading edge of large advancing purple loosestrife infestations, though the risk of nontarget effects increases greatly there. Herbicides are often too costly to be of practical use in treating extensive infestations of purple loosestrife and are also impractical in hard-to-access and environmentally sensitive

Figure 45. Spraying a purple loosestrife infestation with herbicides (Steve Dewey, Utah State University; bugwood.org).

areas. Repeated herbicide applications are usually required through time as purple loosestrife stems can re-sprout from their root system, and new purple loosestrife plants can germinate from the seedbank. The biggest drawback to utilizing herbicides is the extensive damage they do to associated vegetation in the wetland habitats purple loosestrife so readily invades. There is increasing evidence that wide-scale herbicide use favors purple loosestrife by having more detrimental and long-term impacts on competing species. For these reasons, herbicides are best used as a minor part of a larger, integrated weed management program that employs other weed control methods.

Herbicides are recommended only for very small purple loosestrife infestations and where they can be applied to purple loosestrife only (spot treatments). Herbicides must never be broadcast over large areas where damage to desirable species and long-term effects on the ecosystem are likely. Selective herbicides are those that target selected species while leaving other species virtually unharmed. Utilizing only selective herbicides against purple loosestrife will further decrease the amount of damage to nontarget species.

Most herbicides currently registered for use against purple loosestrife work best when applied while the weed is actively growing, especially when the weed is in the flowering stage in late summer or early fall. Herbicides applied in spring or early summer can kill purple loosestrife stems, but new stems can sprout from the root system or new seedlings can germinate before winter. Clipping purple loosestrife stems prior to applying herbicides may increase herbicide efficacy. Clipping purple loosestrife stems below the flowers may allow the plant to continue to grow and absorb more of the herbicide, while clipping too low may encourage the plant to abort the treated stem and send up new stems instead.

When herbicides are used against purple loosestrife, it is important that the applicator adhere to all label instructions to ensure the usage, surfactant requirement, application rate, application timing and location of herbicide application are ideal. Not all herbicides are registered for use against purple loosestrife in all settings (including on or near water), or for use in each state of the USA and in Canada. Many herbicides are restricted use and can only be applied by a certified and licensed applicator, and then only under specific conditions. Please consult your local weed control authority or county agricultural extension agent to learn which herbicides work best for purple loosestrife control and when to apply them in your area.

Some of the most widely used herbicides to combat purple loosestrife in North America include:

- Glyphosate is the herbicide most commonly used against purple loosestrife. Formulations are available for use in aquatic environments. It is highly effective when applied against the flowering stage in late summer. It can also be effective earlier in the season against pre-flowering plants, though follow-up treatments against surviving plants are recommended. **It is a non-selective herbicide and should only be used in spot treatments and in situations where loss of nontarget vegetation is acceptable.** Glyphosate use should be accompanied by revegetation of desirable species.
- Triclopyr should be applied to flowering purple loosestrife, typically in late summer. It can also be effective earlier in the season against pre-flowering plants, though this stage of plant growth can be difficult to see. It is a broadleaf herbicide so will not harm grasses, sedges, cattails, or other monocots.
- Imazapyr can be applied anytime purple loosestrife is actively growing. Care should be taken pre-flowering as loosestrife plants can be difficult to see. **It is a non-selective herbicide and should only be used in spot treatments and in situations where loss of nontarget vegetation is acceptable. It is soil-active so can harm other plants rooted in the general area or even downhill.** As such imazapyr can interfere with revegetation efforts. Extreme caution should be used if considering this herbicide.
- 2,4-D should be applied to actively growing purple loosestrife in spring and summer. Care should be taken, as this is the pre-flowering stage so plants can be difficult to see. It is a broadleaf herbicide so will not harm grasses, sedges, cattails, or other monocots. This compound has been used successfully in combination with dicamba on pre-flowering purple loosestrife individuals. 2,4-D alone and in combination with dicamba is less effective against flowering plants.
- Dicamba should be applied when purple loosestrife is in the pre-flower stage in spring and summer. Care should be taken in this stage as plants can be difficult to see. It is often mixed with other herbicides (especially 2,4-D) to increase weed control results. This herbicide provides good control of purple loosestrife, but has a shorter soil residual period, so follow up monitoring and timely re-treatments (alone or in combination with 2,4-D) may be needed to prevent reinvasion by purple loosestrife seedlings. **There is some residual activity of dicamba, and this herbicide may kill desirable legume species.** It does not kill grasses, sedges, cattails or other monocots.

If treated areas are grazed by livestock or wildlife, it is important to keep animals out of the site until after the herbicide's label requirements for reentry are satisfied.

Herbicide use can often reduce the spring and summer feeding activities of the *Galerucella* spp. and *Nanophyes marmoratus* as well as the adult stage of *Hylobius transversovittatus* as their food source is destroyed. The actions of herbicides and the root-feeding larvae of *H. transversovittatus may* be complementary in certain locations or habitats, though hard evidence is lacking. Keep in mind that herbicide use is only appropriate for very small infestations, while biological control is appropriate for more established populations. Plants partially or fully defoliated by leaf-feeding biological control agents may not absorb enough herbicide to kill them. One way to successfully combine these two methods is to release biological control agents in a large, main infestation while using herbicides to control small satellite infestations surrounding the main infestation.

Use Herbicides Safely!

Read the herbicide label, even if you have used the herbicide before. Follow all instructions on the label.

Wear protective clothing and safety devices as recommended on the label.

Bathe or shower after each herbicide application.

Be cautious when you apply herbicides. Know your legal responsibility as an herbicide applicator. You may be liable for injury or damage resulting from herbicide use.

Follow all storage and disposal instructions on the herbicide label.

The advantages and disadvantages of purple loosestrife control methods are summarized in Table 9.

Table 9. Comparison of purple loosestrife management options

Control Method	Advantage	Disadvantage	Compatibility with Biocontrol
Biological Control	Is very selective	Some risk of undesirable effects on nontarget plants	*Nanoyphyes marmoratus* should not be released at sites with very high populations of *Galerucella* spp. because heavy defoliation by *Galerucella* reduces food availability for *Nanophyes*. All the purple loosestrife biocontrol agents are otherwise readily compatible with each other.
	Agents generally do not have to be reintroduced once established	Not successful in all situations	
	Public acceptance is generally higher than with other weed control methods	Permanent; cannot be undone	
	Most economical option for large infestations	Measurable changes in weed densities may take many years	
Physical Control (Hand pulling & clipping)	Reduces seed production	Time intensive	Both methods are applicable only to very small infestations where biocontrol is not recommended. Hand pulling is not directly compatible with any biocontrol agent; however, biocontrol can be applied to large, main infestations while hand pulling can be used on surrounding small, satellite populations. Clipping is compatible where *Hylobius transversovittatus* is already present, but it interferes with *Nanophyes* and *Galerucella*.
	Useful for small infestations that must be quickly eradicated	Typically does not kill the plant so must be repeated regularly. (Only kills the plant if the root is completely removed.)	
Physical Control (Tilling & Mowing)	Not recommended for purple loosestrife management		
Cultural Control (Flooding)	Effectively prevents seedling germination	Requires ability to regulate water levels so applicable to only a few water bodies	Compatible with biocontrol if applied in spring and early summer. May kill *Nanophyes* and *Galerucella* spp. if applied in fall and winter. *Hylobius* is tolerant of extended flooding as long as flooding is not year-round.
	Typically not labor intensive	Once water recedes, purple loosestrife seedlings often germinate	
	Does not leave harmful chemical residue or introduce new species	Ineffective against established purple loosestrife plants emerging from water	
		Detrimental to many native or desirable species	
Cultural Control (Re-seeding)	Can be used to restore native species	May be ineffective if existing purple loosestrife stand is dense	Compatible if biocontrol agents are introduced after competitive species are established, or if re-seeding is used following significant control by *Galerucella* spp.
	Can be self-perpetuating	Expensive for large areas	
Cultural Control (Burning & Grazing)	Not recommended for purple loosestrife management		
Chemical Control	Fast acting	Expensive for large areas	Herbicides are applicable only to very small infestations where biocontrol is not recommended. Compatible when using biocontrol on a main infestation and herbicides on surrounding small, satellite infestations. Plants heavily defoliated by *Galerucella* spp. may not absorb enough herbicides for the chemicals to be effective.
	High success rate for reducing purple loosestrife individuals in some settings	Harms desirable vegetation	
	If applied correctly and repeatedly, can be used to eradicate very small populations of purple loosestrife	Public resistance to chemical controls	
		Regulations or policies may prohibit use in some areas	

Glossary

abdomen	The last of the three insect body regions; usually containing the digestive and reproductive organs
adventive	Species that arrived in the geographical area from elsewhere by any means, but is not self-sustaining and whose numbers are only increased through non-reproductive means, unlike a naturalized species
aerenchyma	A spongy tissue with large air spaces found between the cells of the stems and leaves of aquatic plants, providing buoyancy and allowing the circulation of gases
alternate	Where leaves appear singly at stem nodes, on alternate sides of the stem
annual	A plant that germinates, flowers, and dies all in the same year
antenna (pl. antennae)	In arthropods, one of a pair of appendages on the head, normally many jointed and of sensory function
app	A self-contained program or piece of software designed to fulfill a particular purpose; an application, especially as downloaded by a user to a mobile device
aspirator	An apparatus used to suck insects into a container. Can be as simple as in a mouth aspirator, or mechanical as in a gasoline- or battery-powered vacuum aspirator
basal	Located at the base of a plant or plant part
biennial	A plant that flowers and dies between its first and second years and does not flower in its first year
biological control	The reduction in the abundance of a pest through intentional use of its natural enemies (predators, parasitoids, and pathogens)
bolting	Plant stage at which the flower stalk begins to grow
bract	A small, leaf-like structure below a flower
capsule (from plant)	A pod or seed vessel made of two or more cells, which becomes dry and splits open when mature to release its seeds (see “head capsule” for capsule from insect)
cuticle	The wax layer lining the epidermis of plant leaves, preventing dehydration
complete metamorphosis	A life cycle with four distinct stages (egg, larva, pupa, adult)

compound eyes	Paired eyes consisting of many facets, or ommatidia, in most adult Arthropoda
coordinates	A set of numbers used to specify a location
density	Number of individuals per unit area
diapause	Period of dormancy in insects
dicot	Plant with two seed leaves upon germination, including most common flowering species, excluding grasses, sedges, cattails, lilies and orchids
dissemination	Dispersal. Can be applied to seeds or insects
elytron (pl. elytra)	Hardened front wing of a beetle
emergence (insect)	Act of adult insect leaving the pupal exoskeleton, or leaving winter or summer dormancy
epidermis	The outer layer of cells of plant tissue
eradicate	To get rid of something completely
erect	Grows upright and vertical as opposed to prostrate (spreading on the ground)
exoskeleton	Hard, external skeleton of the body of an insect
exotic	Originating in a distant foreign country; not native
fibrous root system	Formed by numerous thin, moderately branching roots
forb	Herbaceous plant (does not have solid woody stems)
frass	Plant fragments, usually mixed with excrement, deposited by feeding insects
genus (pl. genera)	A taxonomic category ranking below family and above species and consisting of a group of species exhibiting similar characteristics. The genus name is followed by a Latin adjective or epithet to form the name of a species
GPS	Global Positioning System; a space-based navigational system providing location and time information by using four or more satellites
grub	A soft, thick-bodied, C-shaped beetle larva
head	Insect segment with the mouthparts, antennae, and eyes
head capsule	Hardened covering of the head of an immature insect
herbivory	Feeding on plants
host	The plant or animal on which an organism feeds; the organism utilized by a parasitoid; a plant or animal susceptible to attack by a pathogen
host specificity	The highly-evolved, often obligatory association between an insect and its host (i.e. plant). A highly host-specific insect feeds only on its host and on no other species
inflorescence	The flowering part of a plant
instar	The phase of an insect's nymphal or larval development between molts
invasive	Tending to spread prolifically and undesirably or harmfully
larva (pl. larvae)	Immature insect stage between the egg and pupa (examples include grubs, caterpillars and maggots)

litter	Dead plant material, such as leaves, bark, needles, and twigs, that has fallen to the ground
margin (of leaf)	The edge of a leaf. Margins typically fall within a handful of categories and are useful in plant identification
membranous	Thin and transparent
molting	Process of insect development that involves shedding its exoskeleton and producing another for the next instar
monocot	Plant with only one seed leaf upon germination, including grasses, sedges, cattails, lilies, and orchids
monoculture	An area vegetated by a single plant species
NAD 83	North American Datum, the official datum used for the UTM geographic coordinate system in North America
native	Of indigenous origin
node	Part of the stem of a plant from which a leaf, branch, or root grows
nontarget effect	When management treatments affect a species other than the targeted species (can be positive or negative)
nymph	Immature form of invertebrates that undergo gradual metamorphosis. Resembles adults
opposite	Where leaves appear in twos at stem nodes, on opposite sides of the stem
oviposit	To lay or deposit eggs
perennial	A plant that lives for more than two years
petiole	Leaf stalk that attaches it to a plant stem
prostrate	Grows flat along the ground as opposed to growing erect (upright)
pupa (pl. pupae) (v. pupate)	Non-feeding, inactive insect stage between larva and adult
qualitative	Measurement of descriptive elements (e.g., age class, distribution)
quantitative	Measurement of quantity; the number or amount (e.g., seeds per capitula)
rhizome	A modified stem of a plant that grows horizontally underground, often sending out roots and shoots from its nodes
root crown	Part of a root system from which the stem arises
rosette	A compact, circular, and normally basal cluster of leaves
senescence	Final stage in a plant's life cycle
species	A fundamental category of taxonomic classification, ranking below a genus or subgenus and consisting of related organisms capable of interbreeding
spiked flowers	Cluster of stalk-less flowers that grow on an upright stem of a plant
stalk	The slender attachment or support of a leaf, flower, or fruit in many plants
subshrub	Short woody plant, often used interchangeably with "bush"
synchrony	Occurring at the same time (e.g., plant flowering and insect oviposition)
taxonomy	The classification of organisms in an ordered system that indicates natural relationships. The science, laws, or principles of classification; systematics

thorax	Body region of an insect behind the head and abdomen, bearing the legs and wings
toothed	Leaf margin that is regularly incised, such as for a saw
transect	A straight line of varying length along which plants are periodically sampled individually or in quadrants
UTM	Universal Transverse Mercator, a grid-based geographic coordinate system
weed	A plant growing where it is not wanted
WGS 84	The World Geodetic System, a datum for latitude/longitude geographic coordinate systems
whorled	Where multiple leaves radiate outward from a single stem node

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Appendix I: Troubleshooting Guide: When Things Go Wrong

This guide is intended to assist those who encounter problems when establishing a purple loosestrife biological control program. It identifies the probable cause of typical problems and offers solutions.

Problem	Probable Cause	Solution
Biological control agents unhealthy or dead when received	Physical damage to agents in transport	Provide adequate packing material to minimize movement of containers and ice packs.
	Drowning	Do not put water in containers during transport; prevent accumulation of excess moisture; too much plant material causes condensation.
	Excess or prolonged heat or cold	Keep containers cool at all times; use coolers and ice packs; avoid exposure to direct sunlight while in transit.
	Starvation	Put purple loosestrife foliage (no flowers, seeds, or roots) in containers.
	Redistribution time	Transport or ship agents immediately after collection.
		Release agents at new site immediately upon arrival or receipt of agent (provided it is still only during the cool hours of the day to prevent rapid dispersal).
	Parasitism and/or disease	Check source agents. Ensure the insect population is disease-free when collecting or receiving shipment.
Reproductive problems	Agents past reproductive stage	Collect at peak activity (i.e. insects are mating and ovipositing).
	Sex ratio: not enough males or females	Collect at peak activity; observe mating among target agents before collecting.
	Agents not synchronized with the purple loosestrife growth stage	Collect agents from sites with plants in similar growth stages.
Few biological control agents collected	Collection at wrong time	Refer to Table 7 for collection time and technique.
	Collection technique	Biological control agents can be killed/damaged during sweeping or aspirating so sweep lightly; avoid debris.
	Conditions at time of collection wrong	Refer to the Chapter 4 section ”Collecting Purple Loosestrife Biological Control Agents” for guidelines on desirable weather conditions.
	Population insufficient	Only collect from well-established populations.
Agents not found after release	Site is unsuitable or too small	Refer to the Chapter 4 section ”Selecting Biological Control Agent Release Sites.”
	Not enough agents released	Release at least 100 *Hylobius*, 200 *Nanophyes*, 200 *Galerucella* in spring or 2,000 *Galerucella* in summer.
	Pesticide use/mowing in area	Select sites where land usage does not interfere with biological control agent life cycles.
	Released on wrong species	Ensure purple loosestrife and the correct biocontrol agent are used.
	Released at wrong time	Release only during the correct plant stage, preferably in the spring rather than summer, and in the cool hours of the day.
	Agents not well adapted to conditions	Release field-collected biocontrol agents wherever possible rather than greenhouse-reared adults
	Ants or other predators preyed upon biocontrol agents	Release only at sites with no obvious ant mounds or high insect predator populations (e.g. mice, voles).
Cannot locate release site	Location marker not obvious	Use bright-colored wooden, metal, or plastic stake.
	Site destroyed	Communicate with all direct and neighboring land users.
	Map poorly/incorrectly drawn	Check map; redraw with more detail or add landmarks; GPS.

Appendix II: Sample Biological Control Agent Release Form

Released By: _____ **Release Date:** ___/___/___ (mm dd yy)

County: _____ **State:**_____ **# Released:** _____

Biocontrol Agent: _____ **Date Collected:** ___/___/___ (mm dd yy)

Source of Agents: _____

Life Stage (circle): Larvae Pupae Adults Eggs Other (specify) _____

Land Ownership (circle): Private County State USFS BLM COE BOR BIA/Tribe TNC Other (specify) _____

Legal: T_____ R_____ Sec_____ Q_____ QQ_____ **Lat**: Deg____Min____Sec_____ **Long**: Deg___Min_____Sec_____

ENVIRONMENT

Temperature (°F):_____ **Wind:** Calm Light Moderate Strong Gusty **Wind Direction:** N S E W

Weather (circle): Clear Ptly Cloudy Cloudy Rain **Release Time**:_____am/pm

Site Elevation:_____

Disturbance: (check all that apply, circle most prevalent) Cultivation ___ Fire ___ Flood ___ Grazing ___ Roads ____ Recreation ____

Directions to Site (include a map to the site on the back of this form):

_____

_____

SITE CHARACTERISTICS

Site Name:_____ **Size of Infestation** (acres):_____ **Weed Cover %:**_____

Weed Height:_____ **Weed Density** (# per meter sq.):_____ **Dominant Plant:**_____

Distribution of Weed: Isolated_____ Scattered_____ Sc-Patchy_____ Patchy_____ Continuous_____ Linear_____

Phenology: Seedling % _____ Rosette %____ Bolt %_____ Bud %_____ Flowering %_____ Seed %____ Dormant %_____

Vegetation Type (check):

- River/Stream bank ☐
- Wetland ☐
- Ditch/Canal ☐
- Lakeshore ☐
- Reservoir ☐
- Wet Meadow ☐
- Dry Meadow ☐
- Other (specify): _____

Comments (continue on reverse if necessary):

Appendix III: Cornell University Purple Loosestrife Monitoring Protocol and Instructions

This monitoring protocol was designed by Cornell University to detect establishment and spread of purple loosestrife biocontrol agents and their impact on purple loosestrife. The protocol can also be used to detect change in herbaceous vegetation relative to change in purple loosestrife. The information included herein has been abbreviated to fit the constraints of this manual. The full protocol can be downloaded from www.invasiveplants.net. Completed forms can be sent to Dr. Bernd Blossey, Fernow Hall, Cornell Univ., Ithaca, NY 14853 for inclusion in the University's larger database.

For best results, monitoring should be conducted twice a year; in late May-early June to assess presence and abundance of the biocontrol insects, and between late August and early October to assess abundance and reproductive activity of purple loosestrife.

Site Selection and Quadrat Setup

Use a two-piece quadrat frame composed of two open-ended "U" halves that snap together to form a square. Construct the quadrat frame from two 10' lengths of 3/4" diameter PVC or CPVC pipe, 4 right-angle elbows and 2 connectors of the same diameter, and PVC or CPVC glue. The inside dimensions of the finished frame should measure 1.0 m by 1.0 m. After cutting the conduit to the correct lengths, glue two elbows to each 1 m long piece (make sure the elbows are perfectly aligned to each other). Then, glue each elbow to a 0.5 m long piece to form two open 'U' shaped half-frames. Glue the connectors to the short sides of one of these half-frames. Using a permanent marker, mark 1 dm intervals on each side to assist with estimating percent cover. The frame can be filled with foam insulation to create a floating quadrat for use in flooded sites. In the field, slide one of the half-frames into position, and then attach the other to it.

Materials needed: 1.0 m^2 quadrat frame, permanent marker, GPS unit (if available), 50 m tape, conduit and hammer, Form 1, pencils, and clipboard.

Ten 1.0 m^2 permanent quadrats should be established at each site. Quadrats should be placed at random into the purple loosestrife infestation. ALL quadrats must contain purple loosestrife; if necessary, shift the location of the quadrat so that purple loosestrife covers at least 30% of the quadrat. Various methods are available to randomize the quadrat placement. The easiest is a transect running through the vegetation with quadrats placed at predetermined intervals

(e.g. every 5, 10, or 20 meters). This method works well in most sites and facilitates relocation of the permanent quadrats. Start at least 5 m from an edge (road, stream, upland etc.). Record the position and numbers of the quadrats on the vegetation map on Form 1. Use GPS coordinates for easy relocation in dense vegetation.

To establish the permanent quadrats, first locate the position of each quadrat, then place the 1 m^2 frame into the vegetation, carefully inserting the arms of the first U-shaped frame through the vegetation and as close to the ground as possible. Then, attach the second half of the frame. Avoid trampling vegetation in and near the quadrat. At each of the four corners drive a 1-2 m (5-8') long plastic or galvanized steel pipe into the ground (galvanized metal electric conduit or PVC pipe are inexpensive and readily available at hardware stores). This will allow exact placement of the quadrat in future years. Write the quadrat number on each conduit with a permanent marker or other means. Allow the pipe to stick up high enough to facilitate relocation, and low enough to minimize vandalism. Quadrats can also be marked with fence poles, and flagging tape can be attached to help relocation. Be aware that too obvious markings can attract vandalism. We have had good success using GPS data to relocate our permanent quadrats even in dense and tall vegetation.

Data Collection

Assessment of insects and plants will occur twice each growing season. Four data forms are provided and described in detail on the following pages: Site location (Form 1), Spring monitoring (Form 2), Fall monitoring (Form 3), and Associated plant species (Form 4). Because different data will be collected at the two sampling times, make sure you have the correct form when sampling. To assess the abundance of biocontrol insects, and the growth of purple loosestrife and other species, a series of estimates are used. All estimates reflect the growth within each quadrat and NOT of the site as a whole, or plants near but not in the quadrat.

Instructions for Form 1: Site Location, Background Information

Site Location: Enter name of the site (for example: Fillmore Glen State Park, north unit: be as specific as possible); and the location (town, county, state, etc.). If Global Positioning System (GPS) coordinates are available, enter this information in the spaces provided.

Contact Person and Legal Landowner: Provide the name, address, telephone number and email address of a contact person. This person can be the releaser or a local contact. If the contact person is not the legal landowner, please provide this information in addition.

Site Characteristics: Check one of the options or provide specifics if none of the options are applicable.

Road Map: Paste a copy of a road map into the space provided. Mark the location of the site. An arrow should indicate North on the map. If a written description of directions is needed, attach the description to this page. Be specific: assume the reader has never been to the locale. Attach additional pages if needed.

Site and Vegetation Map: Provide a map of the area, or copy of an aerial photo, with access roads, approximation of purple loosestrife infestation outlined, other vegetation types, trails, creeks, etc. Paste map into space provided. If insects have been released, indicate with Arabic numerals (corresponding to numbers under Insect Release) points of single or multiple control agent releases. An arrow should indicate North on the map.

Photographs of changes in vegetation over time are a powerful tool for presentations or to reinforce quantitative data. One or several permanent photo-points should be marked in the area of insect release(s) using flagging tape or stakes driven into the ground. The position of these photo-points should be indicated on the vegetation map. The direction in which the picture was taken should also be indicated with an arrow. Take pictures once a year at the same time of the year. The showy flowers of purple loosestrife suggest taking pictures at the peak of the flowering period. Make sure to record which photos were taken from which location and when.

Insect Release History: Document date, control agent species, life stage (adults, eggs or larvae), the number of individuals released, and how individuals were released, as well as time of day and weather conditions. Use additional sheets if necessary. Code each release with an Arabic numeral and insert number at the release point on the vegetation map (see above). Update this information as needed (for example, if additional releases of insects occur).

Instructions for Form 2: Purple Loosestrife Biocontrol Monitoring (Spring)

General: The purpose of this activity is to estimate the abundance of biocontrol insects at the site. Conduct the monitoring in late spring/ early summer, about a month after *Galerucella* adults appear after overwintering at your site. Monitoring is easier with two people, one to make the observations and the other to record data.

Materials: 1.0 m^2 quadrat frame; data sheets (Forms 2 and 4), stopwatch, pencils and a clipboard, permanent marker.

1) **Site information:** Write the site name, state, date, names of investigators, time, weather, and GPS coordinates if known at the top of Form 2.
2) **Position the quadrat:** Carefully approach the quadrat and watch for adults of all three species when you slide the quadrat frame into position. *Hylobius* and *Nanophyes* adults often drop from the vegetation once you touch stems (or even as you approach the quadrat).
3) **Beetle counting:** Use a 1 minute total search time for each insect species released and for each life stage that can be observed. At a site where only *Galerucella* was released, 3 minutes total will be spent searching for eggs, larvae, and adults (one minute for eggs, one for larvae, and one for adults). At a site where only *Hylobius* or *Nanophyes* were released, count only the adults for one minute. At sites with two or three species, count each species separately. Use Chart A to record the category of abundance (I-V).
4) **Estimate feeding damage:** Examine the purple loosestrife leaves and shoots for any evidence of biocontrol agent damage, such as the "shot-hole" feeding pattern of the *Galerucella* beetles. Estimate the percent leaf area removed by insect feeding over the entire quadrat, using Chart B to determine the category (A-G) of damage. Practice estimating the amount of leaf damage with an experienced observer. Initially after release, the amount of leaf damage will be low or non-existent. As *Galerucella* density increases, so too will the amount of leaf damage, which can be very high (> 50%) at high beetle density.
5) **Measuring vegetation cover:** After you have completed the insect counts damage estimates, stand over the quadrat and visually estimate how much of the quadrat is covered by purple loosestrife and how much is covered by cattail (use cover estimates in Chart B). Cattail (*Typha* sp.) is the most common plant associated with wetlands across North America. If you do not have cattail, leave this category blank or substitute with the most common species at your site.

6) **Count stems:** Count the number of loosestrife and cattail stems rooted in the quadrat, beginning at one corner of the quadrat and working systematically across the quadrat. To be counted, a stem must be >20 cm or 8 inches tall and originate within the quadrat; if it originates under the frame, or outside the frame and leans over the quadrat, then it is not recorded. Be careful to distinguish between a stem and a branch; only stems are counted. A stem originates from the ground or within 5 cm of the ground, while a branch originates from a stem at least 5 cm above the ground. In dense stands, it is helpful to look beneath the loosestrife canopy, and to move stems with your hands while counting; this is the easiest way to separate stems from branches.
7) **Other observations:** Record any general observations or useful information; disturbances, flooding, fire, bird nests, etc., for the sample quadrat or the site in general.
8) **Optional:** Record presence (and estimated percent cover, if desired) of all plant species rooted in the quadrat using Form 4.
9) After completing Form 2 for quadrat 1, proceed to quadrat 2, and repeat the process (steps 2-8). Continue until all quadrats have been located and recorded.

Instructions for Form 3: Purple Loosestrife Biocontrol Monitoring (Fall)

General: The purpose of this activity is to estimate the abundance of purple loosestrife and other vegetation in the wetland community, and to record measurements of purple loosestrife plant attributes. Conduct monitoring in late summer to mid autumn. Monitoring is easier with two people, one to make the observations and the other to record data.

Materials: 1 meter stick; 1.0 m^2 quadrat frame; data sheets (Forms 3 and 4); pencils, clipboard, camera, GPS unit

1) **Site information:** Write site name, state, date, names of investigators, time, weather, and GPS coordinates if known, at the top of Form 3. Take photographs at permanent photo points.
2) **Position the quadrat:** Carefully slide the quadrat into position in the purple loosestrife infestation, as close to the ground as possible and being sure not to damage the plants (e.g. break stems). Move stems in or out of the frame so that all stems originating in the quadrat are included.

3) **Estimate percent cover:** Standing near the frame, estimate how much of the quadrat is covered by purple loosestrife and, independently, how much is covered by cattail. Cattail (*Typha* sp.) is the most common plant associated with wetlands across North America. If you do not have cattail, leave this category blank or substitute with the most common species at your site. Use cover estimates in Chart A to estimate percent cover.
4) **Count stems:** Count the number of loosestrife and cattail stems, beginning at one corner of the quadrat and working systematically across the quadrat. To be counted, a stem must be >20 cm or 8 inches tall and originate within the quadrat; if it originates under the frame, or outside the frame and leans over the quadrat, then it is not recorded. Be careful to distinguish between a stem and a branch; only stems are counted. A stem originates from the ground or within 5 cm of the ground, while a branch originates from a stem at least 5 cm above the ground. In dense stands, it is helpful to look beneath the loosestrife canopy, and to move stems with your hands while counting; this is the easiest way to separate stems from branches.
5) **Count inflorescences:** Count the total number of purple loosestrife and cattail inflorescences in your quadrat. Make sure to count only those inflorescences that originate on stems rooted in your quadrat. An inflorescence is the portion of stem above and including the lowest flower bud. Even if only one flower bud is present, it is counted as an inflorescence. Be careful to only count flower buds, and not the small bundles of reddish leaves in the inflorescence axils.
6) **Measure plants:** Select the 5 tallest purple loosestrife stems in each quadrat (if there are fewer than 5 stems/quadrat, measure all that are present). Four measurements will be made on each stem
    a) Measure the stem height (to the closest cm)
    b) Count the number of inflorescences on that stem (including all side branches)
    c) Measure the length (to the closest cm) of the longest inflorescence on this stem (this will generally be the terminal inflorescence)
    d) Remove the central 5 cm portion of this inflorescence. Count the number of flower buds in this 5 cm length of inflorescence. If the plant did not produce any inflorescences or if they are shorter than 5 cm please record this in the appropriate form. Repeat this process for the remaining 4 loosestrife stems.
7) **Measure plants:** Select the five tallest cattail stems. For each stem, measure the height and indicate if it is fertile (lower inflorescence) or sterile (upper inflorescence).

8) **Optional:** Record presence (and estimated percent cover, if desired) of all plant species rooted in the quadrat. Use Form 4.
9) **Other observations:** Record any general observations or useful information, such as disturbances, flooding, fire, bird nests, etc.
10) After completing Form 3 for quadrat 1, proceed to quadrat 2, and repeat the process (steps 2-8). Continue until all quadrats have been located and recorded.

Instructions for Form 4: Purple Loosestrife Biocontrol Monitoring (Associated Vegetation)

General: The purpose of this activity is to monitor the associated ground layer vegetation by recording the presence (and estimated percent cover) of all species rooted in the quadrat.

Materials: 1.0 m^2 quadrat frame; data sheet (Form 4), pencil and a clipboard, permanent marker.

1) **Site information:** Write site name, state, date, names of investigators, time, weather, and GPS coordinates if known, at the top of Form 4. This information needs to be collected at each visit.
2) **Estimate** what percent of the quadrat is unvegetated (i.e., soil, water, plant litter, etc.), and what percent is vegetated; these estimates should total 100%. To make cover estimates more accurate, mentally estimate the unvegetated portion of the quadrat, and compare it to your estimate of the vegetated portion.
3) **Estimate** total percent cover of purple loosestrife and of cattail (copy from Form 2 or 3), and of all other vegetation (other species present that are not purple loosestrife or cattail). Use Chart A for cover categories. If possible, estimate percent cover by life form groups (grasses and sedges; herbs; woody plants). Estimates may exceed 100% due to overlapping of vegetation.
4) **Record:** If you are familiar with vegetation, also record which species are present and estimate percent cover of each species. While it is acceptable to estimate only the most abundant species, these may change over time and it is best to record all species if possible. If any of the plant species are difficult to identify, collect a sample from outside the sampling quadrat for later identification. Consult a botanist before making identification that may be inaccurate. **If you are uncertain, it is better to specify life form over taxonomic identification.**

Form 1: Purple Loosestrife Biocontrol Monitoring - Site Location

Site Name:_____ State:_____GPS: N _____° _____'

Town: _____ County: _____ W _____° _____'

Date: _____ _____ _____
year *month* *day*

CONTACT PERSON:
Name: _____
Address: _____
City:_____
State:_____
Phone: _____ - _____ - _____
e-mail: _____

LEGAL LANDOWNER:
Name:_____
Address: _____
City: _____
State: _____
Phone: _____ - _____ - _____
e-mail:_____

SITE CHARACTERISTICS:
Habitat type: ___River ___Wetland ___Lake ___Meadow ___Irrigation Ditch ___Other

Road Map to Site

Site and Vegetation Map

INSECT RELEASE HISTORY:

Date (year-month-day)	Species	Number and Stage (egg/larvae/adult)	Position of Release On Map (1,2,3,4…)

Form 2: Purple Loosestrife Biocontrol Monitoring - Spring Monitoring

SITE: _____ **STATE:** _____

DATE: _____ _____ _____
year *month* *day*

GPS: N _____°_____'
W _____°_____'

INVESTIGATORS:
Last name *First name*
_____ _____
_____ _____
_____ _____

TIME: _____

TEMPERATURE: _____

WEATHER: _____

Chart A
Insect Abundance (#/stem)

I	1-10
II	11-25
III	26-100
IV	100-500
V	>500

Chart B:
Damage or Percent Cover Class

A	<1%
B	1-5%
C	6-25%
D	26-50%
E	51-75%
F	76-95%
G	>95%

A = Adults Hyl = Hylobius
L = Larvae Nano = Nanophyes
E= Eggs

1 = present
2 = abundant
3 = very abundant

Quad #	Galerucella			Hyl	Nano	Purple Loosestrife			Cattail		Other Insects seen:
	A	L	E	A	A	%damage	%cover	#stems	%cover	#stems	
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											

Notes:

Form 3: Purple Loosestrife Biocontrol Monitoring - Fall Monitoring

SITE: _____
DATE: _____ _____ _____
year month day
INVESTIGATORS:
Last name *First name*
_____ _____
_____ _____
_____ _____

STATE: _____
GPS: N _____o_____'
W _____o_____'

TIME:_____
TEMPERATURE: _____
WEATHER: _____

Chart B: Percent Cover

A	<1%
B	1-5%
C	6-25%
D	26-50%
E	51-75%
F	76-95%
G	>95%

S= sterile
F = fertile

PL = Purple Loosestrife

Quad #	Percent Cover (Chart B)		Number of stems		Number of inflorescences		Purple Loosestrife (5 tallest stems)				Cattail (5 tallest stems)	
	PL	Cattail	PL	Cattail	PL	Cattail	Height (cm)	# of inflores-cences	Length (cm) terminal inflorescence	# Flower buds center 5cm of inflorescence	Height (cm)	S/F
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												

Form 4: Purple Loosestrife Biocontrol Monitoring - Associated Vegetation

SITE: _____ **STATE:** _____

DATE: _____ _____ _____
year month day

GPS: N _____°_____
W _____°_____

INVESTIGATORS:

Last name	*First name*

TIME:_____
TEMPERATURE: _____
WEATHER: _____

Chart B: Percent Cover

A	<1%
B	1-5%
C	6-25%
D	26-50%
E	51-75%
F	76-95%
G	>95%

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Percent of Quadrat (Use Chart B or actual estimates that total 100%)										
Vegetated										
Unvegetated (soil, water, litter, etc)										
Vegetation Cover (Use Chart B; total may exceed 100% due to overlapping of vegetation)										
Purple Loosestrife										
Cattail										
All other vegetation:										
Forbs										
Grasses and Sedges										
Woody plants										
Individual Species (names) (Check if present or use Chart B to indicate percent cover)										

Appendix IV: General Biological Control Agent Monitoring Form

SITE: _____ **STATE:** _____ **DATE:** _____ _____ _____
year month day

Last name: _____ **First name:** _____

GPS: Lat N ____°_____' **Long W**____°_____' **Elevation:** _____ **ft m**

UTM: UTM Datum Zone: __ **UTM Year:** ____ **UTM Easting:** _____ **UTM Northing:** _____

TIME: _____ **TEMPERATURE:** _____ **WEATHER:** _____

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1. Counting Biocontrol Agents

Spend 1 minute counting the adults of each biocontrol agent species separately (*Hylobius, Galerucella*, and *Nanophyes*). Following each count, move to a new part of the infestation and repeat for a total of 5 counts. Record your counts in the table below, and then sum your measurements to determine the total number of adults observed

Sample	*Hylobius*	Sample	*Galerucella*	Sample	*Nanophyes*
1		1		1	
2		2		2	
3		3		3	
4		4		4	
5		5		5	
TOTAL		TOTAL		TOTAL	

2. Estimating Feeding Damage

Walk throughout the infestation and look closely at purple loosestrife shoots and leaves to identify feeding damage by biocontrol agents. Estimate the overall damage by circling the most appropriate choice in the list below.

Agent feeding damage
No agent feeding observed
Occasional, scattered feeding damage observed
Conspicuous, widespread feeding damage observed

Notes: _____

Appendix V: Purple Loosestrife Qualitative Monitoring Form

SITE: _____ **STATE:** _____ **DATE:** _____ _____ _____
year month day

Last name: _____ **First name:** _____

GPS: Lat N ____°_____' **Long W**____°_____'

UTM: UTM Datum Zone: __ **UTM Year:** ____ **UTM Easting:** _____ **UTM Northing:** _____

TIME: _____ **TEMPERATURE:** _____ **WEATHER:** _____

Biocontrol Insect: _____ **Year of release:** _____ ____

Cover class estimate by plant category (Overall infestation, ✓check one for each row)							
	0%	1-5%	6-25%	26-50%	51-75%	76-95%	96-100%
Purple Loosestrife							
Cattail							
Grasses/Sedges							
Forbs							
Shrubs							
Trees							

Dominant plant species on site:
Other noxious weeds:

Estimate purple loosestrife density class (✓check one)			
Flowering plants/m^2		Purple loosestrife distribution	
0		Isolated	
1-25		Scattered	
26-50		Scattered-Patchy	
50-75		Patchy	
>75		Continuous	

Purple loosestrife phenology class	
Loosestrife Stage	Estimated percent
Seedling	
Rosette	
Bolting	
Flowering	
Senescent	

Comments/Observations _____

_____

Appendix VI: Purple Loosestrife Quantitative Monitoring Form

Instructions

General: The purpose of this activity is to estimate the abundance of other vegetation in the community, and to record measurements of purple loosestrife plant attributes. Monitoring is easier with two people, one to make the observations and the other to record data. A transect is made in year 1, with 20 permanent markers inserted along the transect (one marker for each quadrat). All 20 quadrats are re-measured in subsequent site visits (preferably once per year).

Materials needed: 1.1 yd (1 m) measuring stick, 3.5 ft^2 (1.0 m^2) quadrat frame, data sheets, stopwatch, pencils, clipboard, camera, and GPS unit to relocate quadrats.

1) **Site information:** Fill out the site information at the top of the form.
2) **Position the quadrat:** Locate the transect using the GPS coordinates and the permanent markers. Position the quadrat frame along the transect, as close to the ground as possible, along that transect line. Gently arrange vegetation so that plant parts are either within or outside, rather than underneath, the frame, but be sure not to damage the plants. The quadrat should be in the same location as the previous year's quadrat.
3) **Count stems:** Count the number of purple loosestrife stems, beginning at one corner of the quadrat and working systematically across the quadrat. Count the number of flowering (FL) and non-flowering (non-FL) stems.
4) **Measure stems:** Select the four tallest purple loosestrife stems in each quadrat (if there are fewer than four stems/quadrat, measure all that are present). Measure the stem height to the closest cm.
5) **Estimate percent cover:** Standing over the frame, estimate how much of the quadrat is covered by purple loosestrife. Then estimate the percent cover of cattail, grasses/sedges, other forbs, shrubs, water, plant litter, and bare ground. Use cover estimates in Chart A to estimate the percent cover class.
7) **Measure entire transect:** Repeat steps 2-6 20 times at the 20 different quadrats.
8) **Other observations:** Record any general observations or useful information such as disturbances, grazing, fire, etc., for the sample quadrat or the site in general.

Purple Loosestrife Quantitative Monitoring Form

SITE: _____ **STATE:** _____ **DATE:** _____ _____ _____
year month day

Last name: _____ **First name:** _____

GPS: N ____°_____' **W** ____°_____' **Elevation:** _____ **ft m**

UTM: UTM Datum Zone: __ **UTM Year:** ____ **UTM Easting:** _____ **UTM Northing:** _____

TIME: _____ **TEMPERATURE:** _____ **WEATHER:** _____

Chart A: Cover Class	Class	% Cover	Class	% Cover	Class	% Cover	% Cover	Class
	0	0	2	6-25 %	4	51-75 %	6	95-100 %
	1	1-5 %	3	26-50 %	5	76-95 %		

Quad #	Purple Loosestrife Stems						Cover Class (use Chart A)							
	# FL stems	# non-FL stems	Height (cm) of 4 tallest stems				Loose-strife	Cattail	Grasses/ Sedges	Forbs	Shrubs	Water	Litter	Bare ground
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														
11														
12														
13														
14														
15														
16														
17														
18														
19														
20														

Notes: _____